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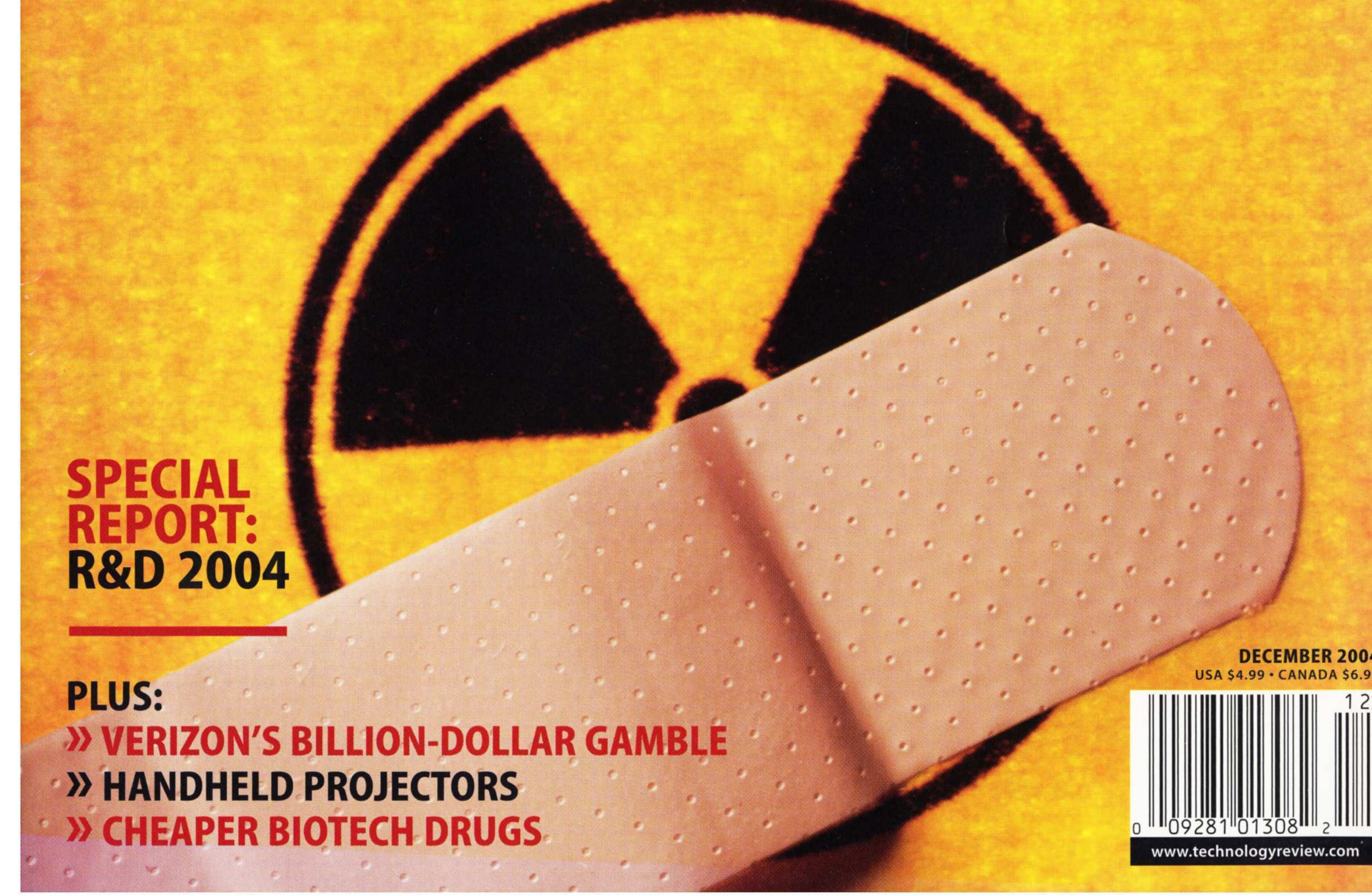

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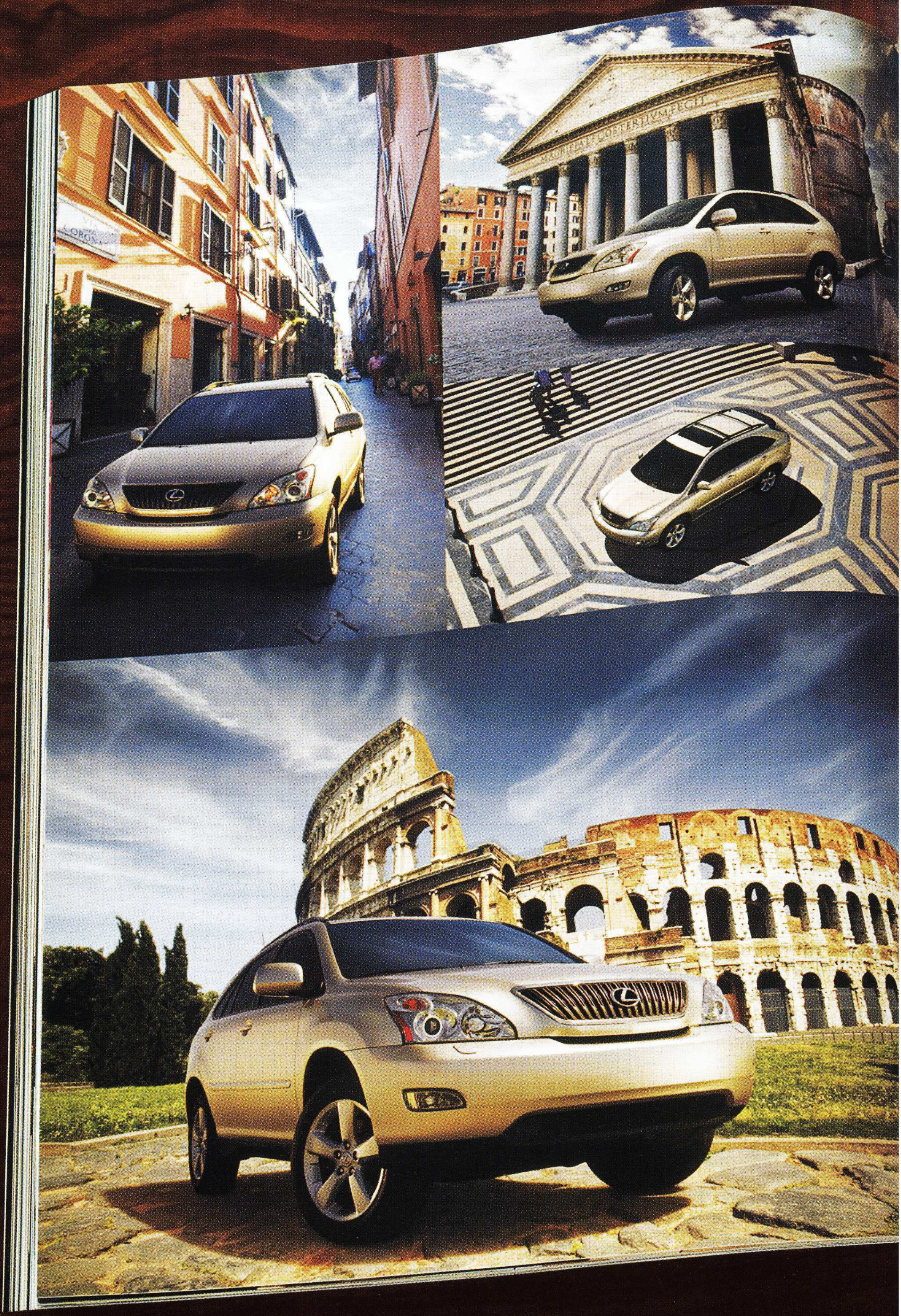

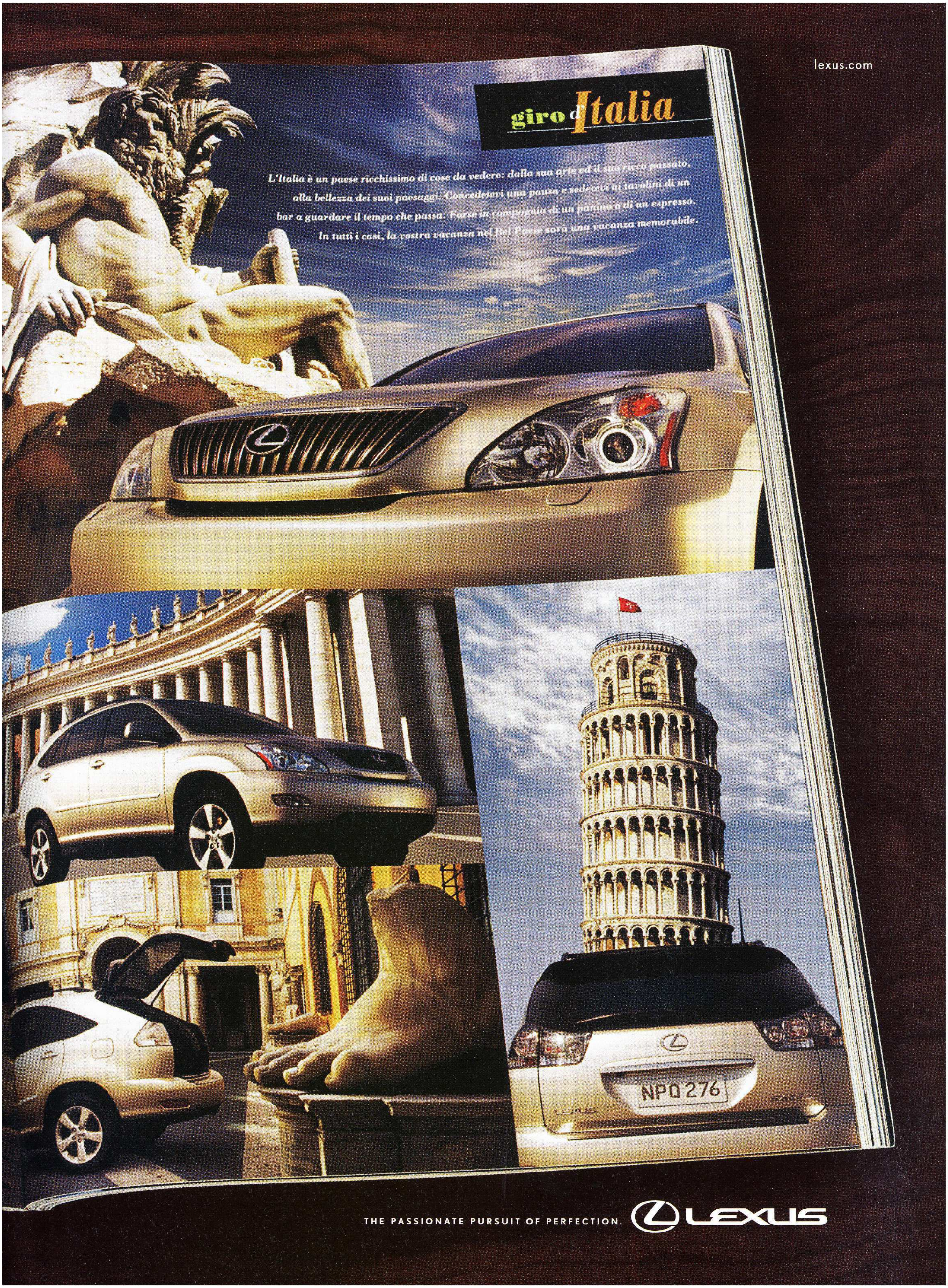

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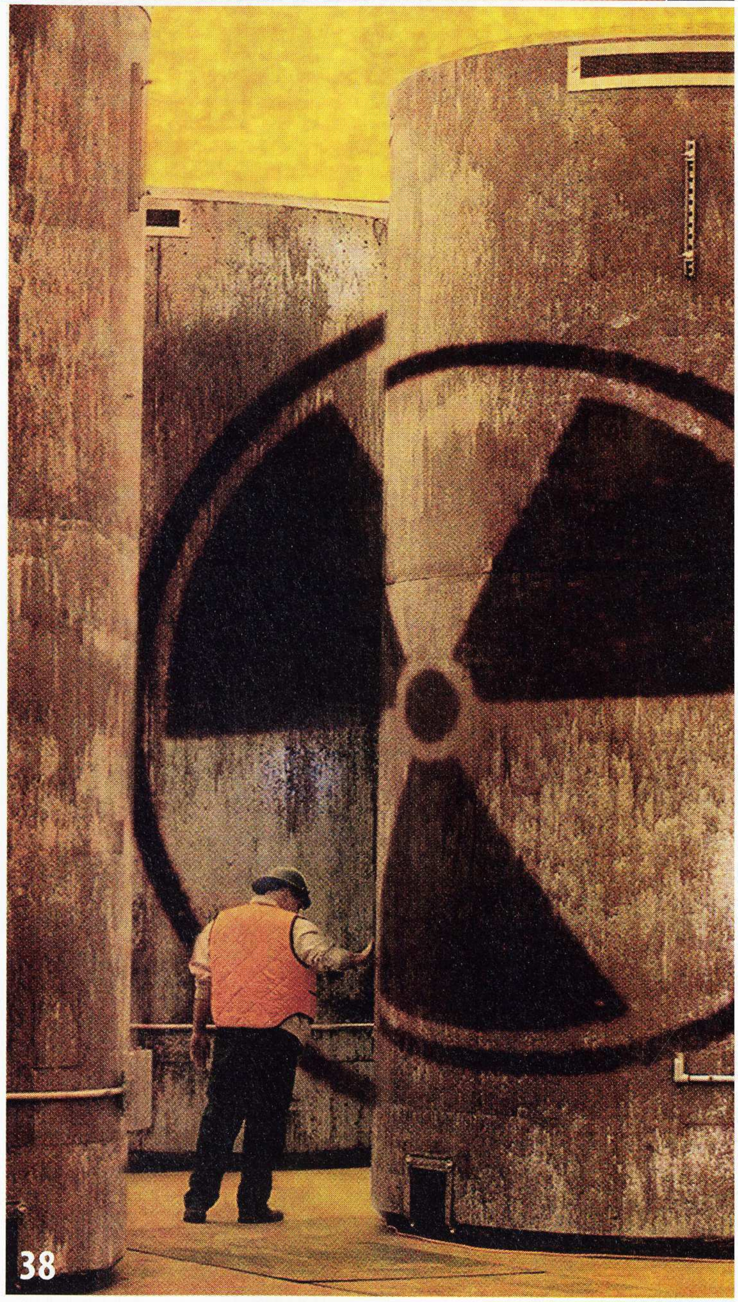
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Cover photoillustration by Stephen Webster

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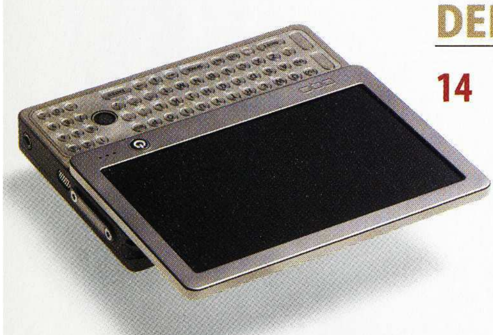
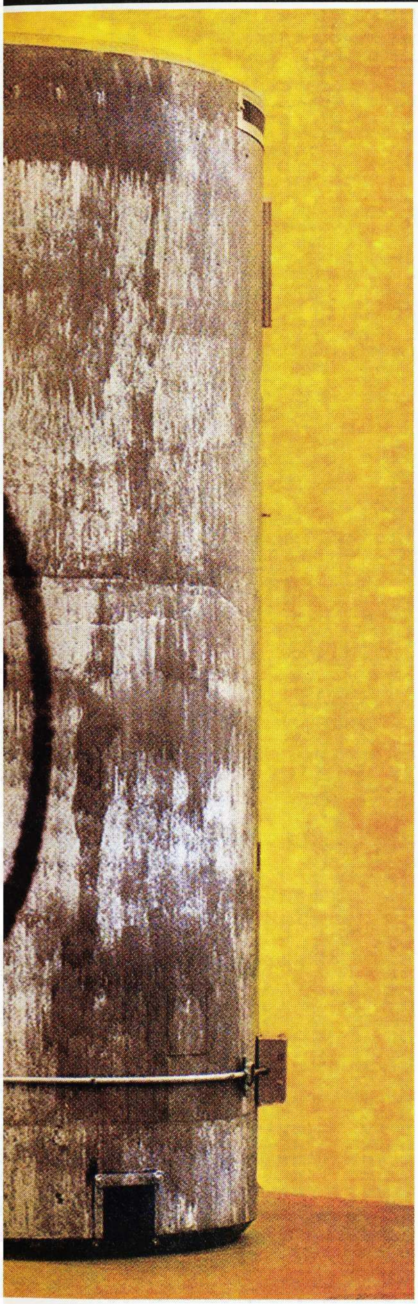
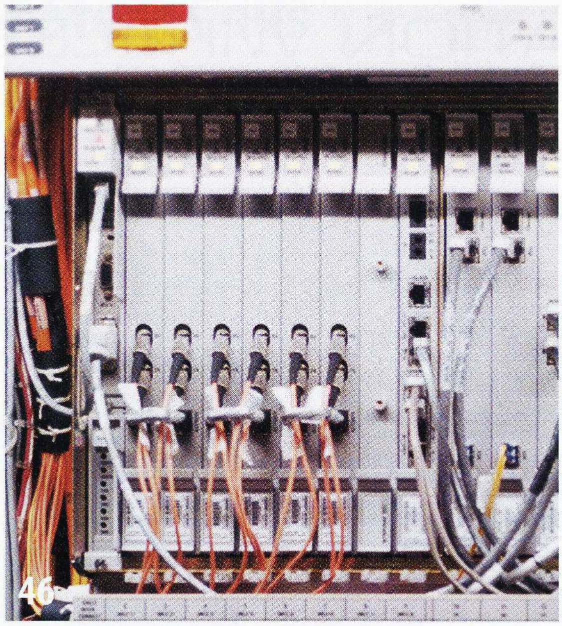


Technology Review
Volume 107, Number 10
December 2004

"People need these drugs for their survival. If they can't afford it, they're dead." —*Abbey Meyers, p. 54*





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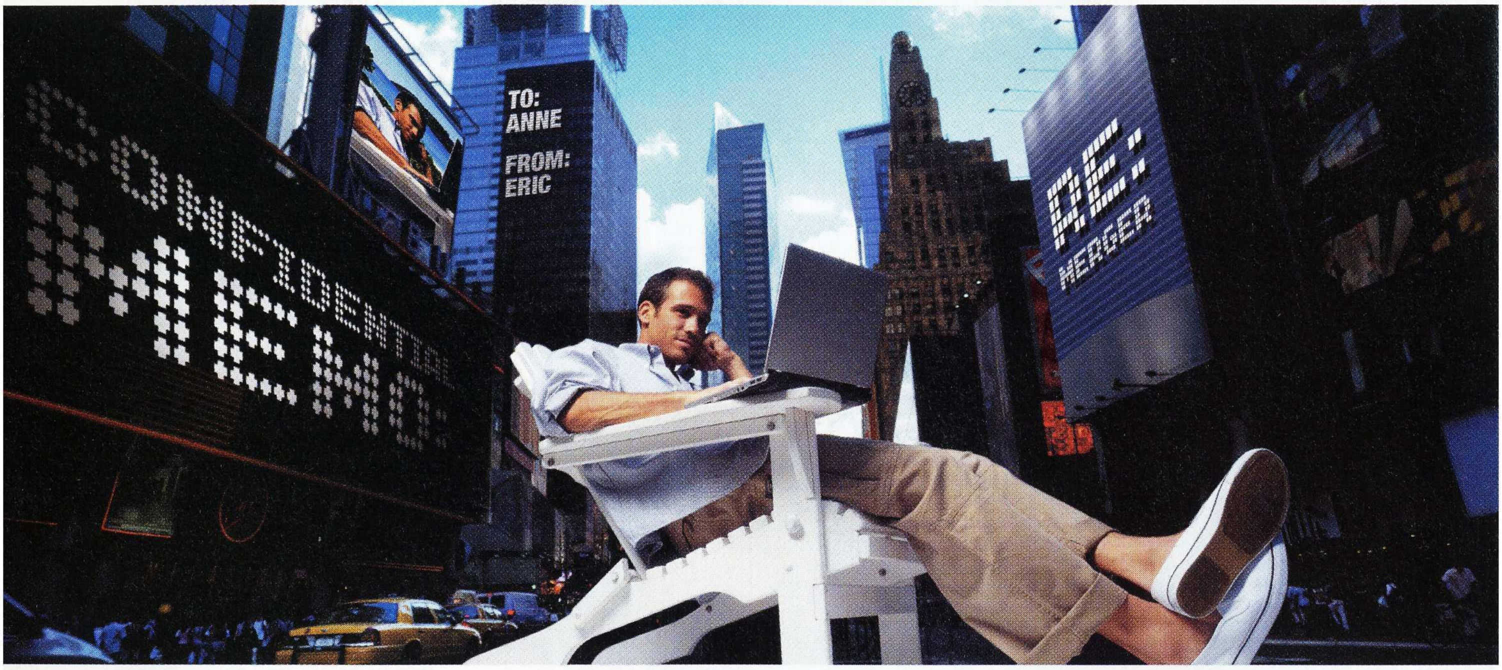
30,000,000 PEOPLE SHARE INFORMATION WIRELESSLY. THE QUESTION IS, WITH WHOM?



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Christopher Reeve and the Politics of Stem Cells

WHEN THE ACTOR Christopher Reeve died in October, in the closing days of the presidential campaign, I was in demand as a guest on news shows. I had published stories about embryonic stem (ES) cells at *Red Herring* and the *Acumen Journal*, two magazines I edited before coming to *Technology Review*. And in May 1998, before my time, *Technology Review* was one of the first magazines to publish a long article on ES cells.

Senator John Edwards suggested that ES cell research might have permitted the quadriplegic Reeve to walk. He implied that President Bush (who opposes ES cell research because human embryos are destroyed in the process of harvesting the cells) was complicit in Mr. Reeve's suffering. That the president was suppressing science for political and religious reasons. Nonsense, retorted defenders of the administration, like senate majority leader Bill Frist: no scientist could say for sure *what* ES cells could do. Certainly, they wouldn't have helped Christopher Reeve.

What, perplexed anchors asked, was the truth?

I explained that ES cells were pluripotent entities, able to differentiate into any kind of cell in the human body (a capacity the writer Christopher Scott winningly calls "a kind of single-celled egalitarianism"). In theory, I said, ES cells might be used to treat any disease caused by cell loss or the loss of cell function—for example, Reeve's spinal-cord injury. But, I warned, there were no avowable examples of ES cell treatments for humans. The nearest thing to ES cell therapy uses adult stem cells, but the treatment is only in trials. Also, Dr. Huang Hongyun, a neurosurgeon at Chaoyang Hospital in Beijing, has removed olfactory ensheathing glial cells—which promote the regeneration of olfactory neurons—from aborted human fetuses and injected them into the spinal cords of over 400 paralyzed patients, but it is not clear how, or whether, his treatment works. (Horace Freeland Judson, author of *The Eighth Day of Creation*, will write about Huang in *Technology Review* next month.)

Any technology must exist in a fallen world of methods and ends, about which men and women can disagree.

For now, I said, the promise of ES cell research is scientific: the cell lines might help us understand the nature and progression of genetic diseases. Nevertheless, I told the anchors, it was very important: researchers might derive from an ES cell line the complete blueprint for a disease like breast cancer. *Both* presidential campaigns were misrepresenting the truth about ES cells and exploiting sympathy for the heroic Reeve.

This argument provoked two thoughts. The first was melancholy: the American public knows almost no biological science. The second was, critics of ES cell research are not really opposed to science and its palliative benefits. They hate a technology.

Scientific knowledge, I wish I had told the TV audience, is a kind of absolute good. No one can reasonably object to understanding cellular disease. But the techniques of scientific research are derived from technology, which is morally neutral. Any technology must exist in a fallen world of methods and ends, about which men and women can disagree. Our elected officials may, for political reasons or from genuine conviction, choose to regulate a technology. If enough of us disagree, we can throw them out of office.

Regardless of whether this issue has a decisive impact on the election, the election is certain to have a decisive impact on the future of ES cell therapy. President Bush, who seems sincerely disgusted by the whole subject, chose to ban federal funding of new ES cell lines. Senator Kerry promised to lift that ban were he elected. Come January, an already polarized debate is likely to become more bitter. **Jason Pontin**

NEXT ISSUE

The January 2005 issue of *Technology Review* marks a new beginning for this magazine. We have made three substantial changes. First, we've reorganized the editorial content. Second, we've made it a top priority to bring the world's very best writers to our pages. And third, we have redesigned the magazine. We think you will like the changes, as well as what has *not* changed: our mission. We will remain relentless in explaining the impact of emerging technologies.

Google: What's Next?
Google is on a collision course with Microsoft to control the very future of search. Charles Ferguson, legendary Silicon Valley entrepreneur, author, and now visiting scholar at the Brookings Institution, examines whether Google has the technology wisdom and market savvy to win in this clash of titans.

China's Medical Miracle?
In a hospital in China, a doctor is injecting patients with cells extracted from aborted fetuses. Is it daring, experimental medicine, or shady, unethical medicine promoted by a researcher eager to gain international prestige? We sent famed journalist Horace Freeland Judson to China to find out.

Robo Neuroscience
Robots are good at the dangerous and the mundane, whether sniffing out land mines or vacuuming floors. But sophisticated robots are also beginning to assume a surprising new role: teaching us how the brain operates.

The Future of Publishing
Jason Epstein knows something about book publishing. In the early 1950s, he helped launch the "paperback revolution." He also spent 40 years as editorial director at Random House. Epstein sees the book business as on the verge of a technology-led revolution—and that, he says, is a good thing.

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17. Signature and Title of Editor, Publisher, Business Manager, or Owner: James Coyle Controller Date: 10/27/04

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"Both geographical and disciplinary barriers are falling away."

KNIGHT OF THE WEB

I WOULD LIKE TO EXPRESS A DIRECT, explicit, and huge thank you to Sir Tim Berners-Lee for magnanimously battling our Internet dragons and winning ("Sir Tim Berners-Lee," *TR* October 2004). His Semantic Web will be the Web to the power of two and will be better than the current version. We are reaching for the Web in four dimensions, connecting past and present to your future calendar, and forming friend-of-a-friend or idea-of-an-idea relationships. That is when the fears about privacy and security will strike. I hope that Sir Tim Berners-Lee or some other brave knight will draw the sword and battle our dragons anew.

Michael Ashley Schulman
Newport Beach, CA

AS A WEB PROFESSIONAL WITH A background in social-marketing and social-change communications campaigns, I found your interview with Tim Berners-Lee a revelation. I can't tell you how much it changed my perspective on this powerful new technology, which I always felt was a social phenomenon. I believe his dream was about a social movement. And I think it is just beginning to come true.

Michael Almond
San Francisco, CA

TR 100: INNOVATION BEYOND TECHNOLOGY

THANK YOU FOR CONTINUING YOUR excellent work with the TR100 (*TR* October 2004). Your review clearly illustrates the ways that both geographical and disciplinary barriers are falling away. I would also suggest that other barriers to innovation are crumbling. For example, we are seeing more and more innovation in the realm of organizational technology, known more commonly as business models. And perhaps an even greater innovation is occurring in the nonprofit sector, as social entrepreneurs launch new ventures that address long-standing social problems in novel and exciting ways. Finally, in both sectors we are seeing innovation at the level of human and group experience. It is time that these social and organizational innovations get the recognition and respect they deserve.

Brendan Miller
Cambridge, MA

COUNTING THE E-VOTES

IF THE "SPOIL RATE" FOR E-VOTES IS only 1 percent, that would be far superior to the current punch-card and optical spoilage rates ("Concerns Grow over E-Voting," Innovation News, *TR* October 2004). We can argue that the 1 percent is more random and isn't as dependent on poorly filling out the ballot, but it would still be an enormous improvement. Perhaps the best compromise would be using electronic machines to print out completed ballots that could then be scanned by optical machines. This way you get the "receipt," but you have to turn it in to get your vote counted. The electronic system could simplify the voting process by offering ballots in multiple languages (for non–native English speakers) as well as in audible form (for the visually impaired). The optical scanning of the printed ballots would mean that there's a paper trail for auditing and recounting if necessary.

Rob Crocker
Bloomfield, CT

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STOPPING VOICE SPAM

THE STORY ABOUT QOVIA'S NEW technology that promises to stop voice mail spam left me unconvinced ("Talking Spam," Innovation News, *TR* October 2004). It seems most anti-spam software for e-mail claims 95 percent success rates or better, yet everyone is still being bombarded with unwanted e-mail. I think we'd better get on the ball with some new idea to stop all this junk and not waste too much time getting excited about the same old "solution."

Eileen McCluskey
Watertown, MA

CLASSIFICATION CLARIFICATION

YOUR STORY "HOW TECHNOLOGY Failed in Iraq" (*TR* November 2004) could give a reader the incorrect impression that Rand researcher Walter Perry commented on a classified Rand report about the war in Iraq. That is not the case. Perry discussed unclassified research findings on what he referred to as the "digital divide"—a situation where front-line troops did not have access to all the surveillance and intelligence data that was available at the division level and above.

David Egner
Director of external communications
Rand
Santa Monica, CA

The editors respond: While the Rand report in question was discussed with *Technology Review* and will, in fact, be classified, Walter Perry and his colleagues were always clear with *Technology Review* that they were talking about unclassified portions of the report.

This 9.4-tesla magnet powers a superhigh-resolution brain scanner.

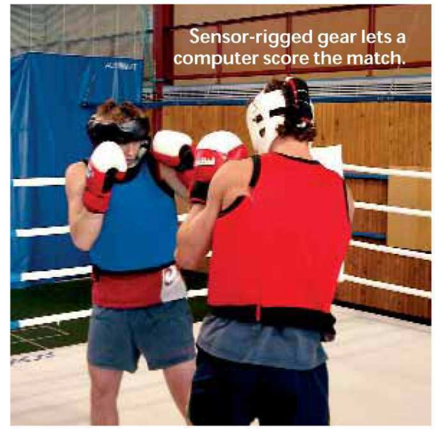
SUPER SCANNER

THE MAGNETIC-RESONANCE IMAGING (MRI) machines that most hospitals use provide only a picture of anatomy—revealing a mass in the brain, for example, but not its precise chemical composition. A new, much more powerful MRI scanner developed by GE Healthcare for the University of Illinois at Chicago can show concentrations of sodium, phosphorus, oxygen, and other elements in the brain. Since many neurological diseases manifest themselves as subtle biochemical changes long before anatomical changes are apparent, this scanner could enable earlier diagnosis of conditions such as Alzheimer's disease and mental illness. Doctors and drug developers could also use it to more precisely and directly measure the effects of drugs on the brain. Thanks to 550 kilometers of superconducting wire, the scanner induces a magnetic field that's three times stronger than even a state-of-the-art MRI machine's, so it can pick up the weak signals from sodium and other atoms and image them with triple the resolution. While it may be many years before the new scanner can be mass-produced for hospitals, the researchers plan to begin the first human tests of the technology, pending regulatory approval, by the end of this year.


Realistic joints in this digital skeleton could aid animators and doctors alike.

VIRTUAL ORTHOPEDICS

GOT BAD JOINTS? SO DO MOST COMPUTER MODELS of the human body, because they neglect nuances of anatomy and physics. That can make animated characters look fake—or worse, make virtual surgeries and digital crash-test dummies inaccurate. Now computer scientists have developed software that more realistically simulates the complex movements of human joints. Victor Ng-Thow-Hing at Honda Research Institute USA in Mountain View, CA, and New York University's Wei Shao model the human shoulder, for instance, as four separate joints instead of just one. Specify the geometry of the upper arm, collarbone, scapula, and rib cage, and the computer does the math to figure out how they all interact when, say, a virtual athlete throws a ball. A graphical interface lets animators and other users add layers of complexity to each joint to produce more detailed behaviors, such as bones slipping with respect to each other. Video game developers have expressed interest, says Ng-Thow-Hing, but biomedical applications are still a few years away.


Sensor-rigged gear lets a computer score the match.

TECHNOLOGICAL KNOCKOUT

BOXING IS A SPORT OF BRAWN, BUT AN Australian researcher is out to show that an electronic brain can aid training and make fights fairer. Engineering student Kane Partridge at Swinburne University of Technology in Victoria embedded impact sensors in the gloves, vests, and headgear of a pair of boxers and connected the sensors to a ringside computer via a wireless link. The computer records every punch thrown, analyzes the blows in real time, and scores the bout, noting illegal punches and ignoring ones that miss. Partridge hopes the system, built for the Australian Institute of Sport, will allow coaches to identify boxers' strengths and weaknesses and let the fighters study blow-by-blow accounts of their performances. It could even replace human judges in bouts.

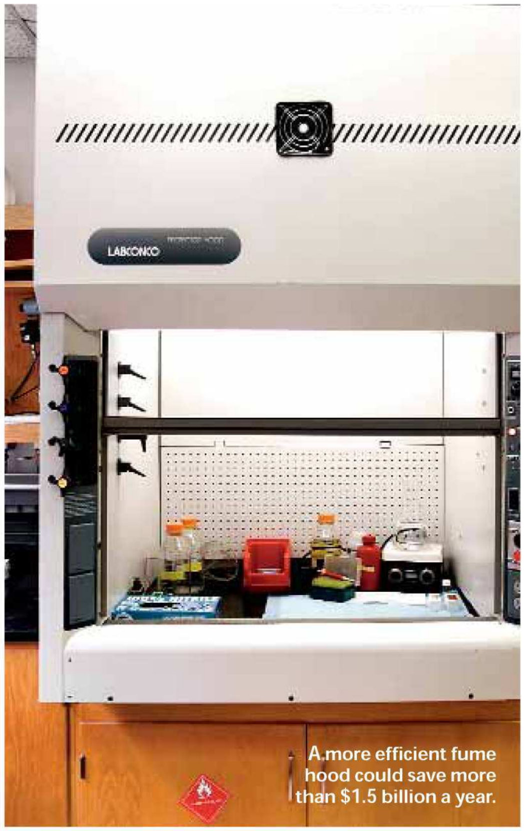
BETTER BATTERY GAUGE

Your laptop's battery gauge says you have an hour of computing time left, but don't count on it. The older a lithium-ion laptop battery, the less energy it can typically store—a variation that can throw off the accuracy of conventional battery gauges by more than 50 percent. This winter, Texas Instruments plans to introduce an inexpensive "gas gauge" chip that not only takes into account a battery's original capacity but also measures its impedance—the resistance to electrical current caused by age, frequent use, and other factors. Built into the chip are mathematical models of lithium-ion chemistry that use impedance measurements to calculate how much a battery has degraded and adjust predictions of remaining charge accordingly.

COURTESY OF VICTOR NG-THOW-HING (ORTHOPEDICS); ROBERTA DUPUIS-DEVLIN/UIC PHOTO SERVICES (SCANNER); COURTESY OF KANE PARTRIDGE (KNOCKOUT)

CHEAPER SUCKER

RESEARCHERS AT THE U.S. DEPARTMENT OF ENERGY'S LAWRENCE BERKELEY National Laboratory in Berkeley, CA, believe they can save the country more than $1.5 billion a year in electricity by updating the 60-year-old-design of a laboratory staple: the fume hood. There are close to a million fume hoods in the United States, protecting high-school chemistry students and industry researchers alike by sucking up airborne chemicals, microbes, and particles. But hoods also suck up a lot of power: a typical one uses more energy each year than three homes. The key to the efficiency of the Berkeley Lab's design is small fans at the top and bottom of the hood opening that create a curtain of clean air between the worker and hazardous substances on the countertop. Behind that curtain, a more powerful fan draws out the contaminated air, in much the way a conventional hood's does. But because the fumes are already contained, the new system requires only about a third of the airflow and therefore much less energy. Berkeley Lab researchers and fume hood manufacturers are now field-testing the hoods in operating laboratories.



A more efficient fume hood could save more than $1.5 billion a year.

MOBILE FLOOR

TRAINING AND MILITARY SIMULATIONS CAN IMMERSE users in realistic visual worlds. Now researchers at the University of Tsukuba and the Advanced Telecommunications Research Institute in Japan have developed an interface that lets users negotiate such virtual spaces physically—without bumping into walls. Four square tiles, about 70 centimeters on a side, zip around on motorized wheels to form a moving platform under a person's feet; the user can step in any direction but remain in the middle of the room. Ultrasound and optical sensors on the floor let the system predict where the user is about to step. The tiles communicate with a computer that synchronizes the person's movements with a virtual scene on a head-mounted display. The first application could be in virtual evacuation drills to prepare for disasters such as fires and earthquakes, says Tsukuba engineering professor Hiroo Iwata, whose team is working toward having a commercial product ready within a few years.

Mobile tiles aid virtual navigation.

ANYWHERE INTERFACE

French physicists Ros Kiri Ing and Mathias Fink have figured out how to turn any rigid surface into an interface for electronic systems. The technology—which the pair hope to commercialize via their Paris-based startup, Sensitive Object—uses one or two inexpensive accelerometers to detect finger taps on, say, a storefront display window or a keyboard drawn on a blackboard. A computer chip calculates the precise origin of each tap and translates that information into mouse clicks and keystrokes. Users might use the technology, for example, to "click" on a storefront mannequin's hat to learn its price. Ing says the technique has advantages over other user interfaces under development because it can work with a surface as large as four square meters, and the number of "keys" can reach 544.

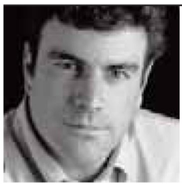
POWER PLAY

NEW SOFTWARE FROM SIEMENS VDO Automotive in Schwalbach am Taunus, Germany, could boost cars' fuel efficiency by regulating their electricity usage. Seat heaters, navigation systems, and other power-hungry features increase the demands on the alternator and, in turn, the amount of fuel burned. The software, running on the car's various microprocessor units, economizes by briefly siphoning electricity away from low-priority comfort systems, like air-conditioning, and shuttling it to higher-priority safety and driving systems when the car is, for example, speeding up to pass. Siemens researchers, led by electrical engineer Hans Michael Graf, have tested the software in computer simulations and estimate that it can reduce a car's electric-power usage by 70 percent under city driving conditions—without the driver's noticing a difference in performance or comfort. They expect to complete construction of a demonstration vehicle using the system by early next year.

Software running on a car's microprocessors boosts fuel efficiency.

COURTESY OF HIROO IWATA (FLOOR); COURTESY OF SIEMENS (POWER); GEOFFREY C. BELL (SUCKER)

Innovation Diffusion



THIS IS MY LAST COLUMN FOR *TECHNOLOGY REVIEW*. Really. It's all over. Why? New editorial directions, new opportunities. Perhaps it's time for a different take on the evolving politics, culture, and economics of innovation. ▪ But I'd be foolish to pass up this final chance to discuss what I've learned—and unlearned—about innovation since this column first appeared in *Technology Review*'s January/February 2002 issue.

My convictions about what innovation can and should mean have changed dramatically. I've wanted this column to be a forum for exploring the real guts and viscera of the innovation process—not the polite entrepreneurial fictions about how brilliant ideas ultimately charm reluctant marketplaces.

Simply put, innovators don't change the world. The users of their innovations do.

Simply put: innovation isn't what innovators *do*; it's what customers, clients, and people *adopt*. Innovation isn't about crafting brilliant ideas that change minds; it's about the distribution of usable artifacts that change behavior. Innovators—their optimistic arrogance notwithstanding—don't change the world; the users of their innovations do. That's not a subtle distinction.

That's also why I now believe that the dominant global issue of our time is the accelerating diffusion of innovation. Period. Full stop. The diffusion of innovation—not the "spread of ideas" or the "clash of civilizations" or even "globalization"—is the dynamic driving today's world and tomorrow's. Whether you care about nuclear-weapons proliferation, the specter of bioterrorism, global warming, the "digital divide," or the prospect that new sources of potable water and cheap energy will better the lives of billions, you are—in the first and final analysis—concerned about the risk/reward rivalry that drives the diffusion of innovation.

Every significant issue of our time—energy crises, environmental degradation, economic development, public health, HIV/AIDS, educational opportunity, child care—is increasingly shaped by the ebb and flow of technical innovation. In fact, the quality of global life and the standard of local living have come to be defined by the diffusion of technology. We're not going to escape this essential truth; it's dishonest to try.

The Big Lie of the Information Age is that "Nothing is more powerful than an idea whose time has come." What nonsense. In reality, nothing in this world is more powerful than an innovation that has diffused to the point where it enjoys both global reach and global impact. Ready access to ideas promotes awareness, but ready access to innovation promotes empowerment and opportunity.

The challenge for policymakers and populations alike is how to cope with the pervasive—and perverse—consequences of ever more people gaining ever greater access to ever more innovations that offer ever greater impact for ever lower costs. Why? Because diffusion is inherently messy and unpredictable, and because the ingenuity of a technology's adopters more than rivals the creativity of its original innovators. We ignore this at our peril.

This new millennium's most excruciating irony is that the rising democratization of innovation disproportionately empowers the most totalitarian and fundamentalist of ideologies. As economist cum nuclear strategist Thomas Schelling has so chillingly documented, the ability of tiny groups of fanatics to kill large groups of innocents has grown by orders of magnitude over the past fifty years. Using home-brewed technologies, reasonably well-funded sociopaths would today find it easier than ever to kill hundreds of thousands of people at a time. Oppenheimer's lament upon witnessing the first nuclear explosion in Alamogordo—"I am become death, shatterer of worlds"—now seems the quaintest of anachronisms. Truly, we ain't seen nothing yet. The monopolies on destruction held by states and sovereigns are rapidly devolving into entrepreneurial opportunities for cults and causes.

Yet at the same time, it's easier than ever for a successful medical device or video game devised in Karachi, Kampala, or Caracas to catch fire and spread swiftly around the world. There has never been a better time to appreciate, explore, adopt, and adapt the ideas and innovations of others. Even in economies constricted by regulation and corruption, enormous gray markets in innovation somehow take root and prosper.

The accelerating spread of innovation ultimately amounts to the greatest revolution in choice the world has ever known. The diffusion of innovation is about the diffusion of choice—both good and bad. The more choices you have, the more your values matter.

Politics aside, the values of this column demand that I end by acknowledging the readers and editors who've taken the time to share their concerns with me over the past two and a half years. It's been gratifying to get responses from so many smart people who care about what I've been saying. Thank you. TR

A researcher and consultant on innovation economics, Michael Schrage is the author of *Serious Play* (Harvard Business School Press, 2000).

STEPHEN SHILDBACH

Beyond the Bar Code

New RFID tags will pinpoint every item, everywhere. **BY WADE ROUSH**

THAT OLD GROCERY-store standby, the bar code on every mop, magazine, and Mars bar, celebrated its 30th birthday this year. Considering the drastic advances in computing since 1974, it should come as no surprise that there's a new product-tracking technology breathing down the bar code's neck.

It's called the Electronic Product Code, and at its core, it's just a long number like the one embedded in a bar code. But whereas bar codes can only be read by laser scanners at close range, EPCs are stored in radio frequency ID (RFID) chips affixed to product packages, which radio-wave scanners can read at a distance of up to several meters. While all bags of Oreos bear the same bar code, Electronic Product Codes have so many digits that each bag could receive its own—as could up to a billion billion other items.

The EPC is part of an ambitious scheme to create a global, standardized network for tracking everything that's shipped, stocked, and sold. This "Internet of inventory" will give manufacturers and retailers a God's-eye view of their universe, potentially saving them billions of dollars collectively by highlighting shifts in demand sooner and averting overstocking and understocking. Even consumers should notice the change. "The benefits just in the short term are that you'll have better availability of products, better freshness of perishable products because things aren't stopping to be counted, and it will be harder for people

to steal things," says Kevin Ashton, vice president of marketing at ThingMagic, a maker of RFID readers in Cambridge, MA. "All those greater efficiencies should lead to lower prices and better service."

The ideas behind the EPC have been brewing for years. Big organizations like Wal-Mart, Target, and the U.S. Department of Defense have already spent millions on RFID technology in order to get better snapshots of their supply chains and ensure that products go where they're needed, when they're needed. What's changed is that the same efficiencies will soon be available to all companies, thanks to the emergence of common methods for storing, reading, and transporting RFID data. In October, after a year of wrangling, a score of rival RFID companies put aside their differences and settled on a global EPC standard. A final ratification vote was still pending at press time, but the near completion of the standard means that manufacturers and retailers can start testing and deploying the newest RFID equipment and software, safe in the knowledge that every reader can read every tag and that every organization's product database can tap into every other's.

Ashton says the key to consensus was convincing makers and users of RFID technology that the tags themselves should be as simple—and therefore as cheap—as possible. "An RFID tag is not a portable database. It's just a small chip that contains a number—a tiny little network node that does nothing more than to point you at data available somewhere else," says Ashton, who is also the former director of MIT's Auto-ID Center, where the idea for the EPC was born. "That may sound like a tiny thing, but in the 1990s the RFID industry was convinced that it was in the portable-database business, and there was an incredible holy war that we fought for several years." The new EPC standard not only specifies a common format for the codes but creates a uniform system for matching the codes with detailed product information, which can be stored anywhere on the Web.

Hardware based on earlier drafts of the EPC standard is already hitting the market. ThingMagic, for one, is making RFID readers able to use multiple frequencies to read tags. "You need that flexibility because radio regulations are different around the world, but supply chains are global," says Ashton. "You want to be able to read a product in China where it's made, translate that for DHL, read the shipping containers for homeland-security reasons when they come into port, then keep track of the stuff domestically."

The new "Internet of inventory" will give manufacturers and retailers a God's-eye view of their universe, saving billions.

Bigger players like IBM are getting into the EPC act, too. IBM is building software that will use the EPC standards to synchronize product data across the computing systems of entire chains of trading partners, eliminating costly errors and safety lapses. Says Dan Druker, director of product information management solutions for IBM, "You'll know all the physical information about the product—not just the price, but all of the policies associated with it. Like, if it's broken, what do I do with it? If it's exposed to high temperatures, what does that mean? How should it be stored? What can it be put next to?"

And that's good for consumers, not just businesses, says Sue Hutchinson, a product manager for the U.S. branch of EPCGlobal, the industry consortium overseeing the standard. "The first way my aunt or my grandmother are going to see this is that they're going to open the Thursday afternoon circular from the XYZ store, and when they go on Saturday they'll be guaranteed their products will be there," Hutchinson says. "For my grandmother, there may over time be additional benefits from her pharmacy, in guaranteeing the safety and availability of her prescription medications." There could even be a time, says Hutchinson, when an in-home RFID reader will scan her grandmother's pill vials and remind her when to take her medicine.

If the technology stays on track, it is certain to alter the average consumer's shopping experience. "The Holy Grail is the checkoutless supermarket, where you just wander out the door" and your selections are automatically scanned and charged to your credit card, says Ashton. But "that's not going to happen until 2011 at the very earliest," he says. First, there's the matter of the RFID chips themselves: the entire EPC scheme assumes that the cost per chip will drop from an untenable 20 to 50 cents today to a nickel or less. At the same time, companies must modify their back-room supply-chain software to work with the EPC standard, then apply the tags to every pallet, case, and package. And in a world where many smaller merchants haven't even adopted bar code scanners, that could be a lengthy process. TR

A SAMPLE ELECTRONIC PRODUCT CODE

01•0000A89•00016F•000169DCO

Header	EPC manager	Object class	Serial number
Shows which version of the EPC standard is being used	Identifies the item's manufacturer	Refers to the product type, such as "Coca-Cola 330 milliliter can"	Unique to the item: "This exact can of Coca-Cola"

SOURCE: EPCGLOBAL

MEDICINE

Scaffolds for Stem Cells

DESPITE THE HIGH HOPES surrounding stem cells' potential to form replacement tissue for medical use, biologists are still struggling in the lab to get these finicky cells to transform into the needed tissues. Now Cartilix, a startup in San Carlos, CA, is offering a technology that might help: polymer materials that direct the growth and development of stem cells.

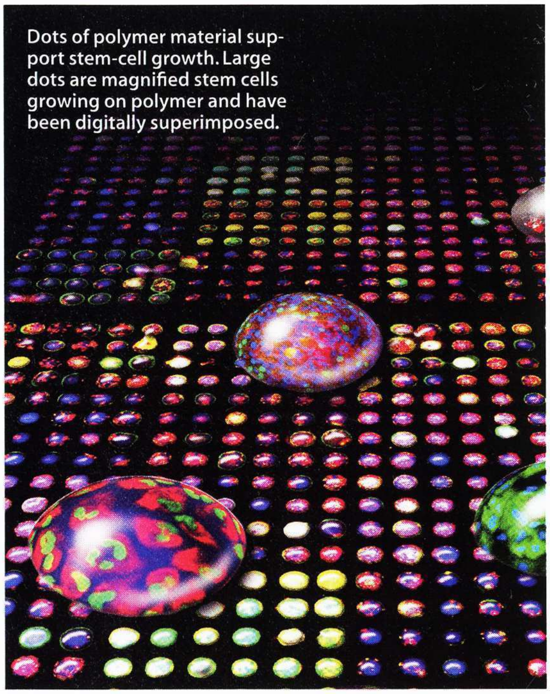
The startup is working on polymer gels that would be implanted into the joints of arthritic patients and serve as scaffolds upon which the patients' own bone marrow stem cells would form new cartilage. The stem cells would come from the blood that naturally seeps into the joint area during the implantation procedure; after new tissue forms, the polymer would biodegrade. The hope is that this treatment will help patients "get their own cartilage back" and avoid joint replacement surgery, says Frank Huerta, Cartilix's CEO.

Stem cells require cues from their environment—including growth factors secreted by other cells and even mechanical pulling forces—in order to transform into more mature and specialized cells and tissue. Scaffolds can provide those cues, says Jennifer Elisseeff, a biomedical-engineering professor at Johns Hopkins University and Cartilix's scientific cofounder. With these scaffolds, "our goal is to mimic what the cells normally see in the body," she says. Cartilix's gels, for example, would be infused with growth factors that encourage the growth of the right kinds of cartilage.

Cartilix isn't the only group combining polymers with stem cells. MIT researchers are growing human embryonic stem cells on hundreds of polymer materials to test their interactions *(see photo)*. But Cartilix stands out because its treatments wouldn't involve cell transplants; rather, the polymer would prompt the patient's own cells to form new tissue. Stem-cell-based treatments remain years away, but Cartilix and its competitors may have provided a scaffold they can grow on. **Corie Lok**

OTHERS IN BIOPOLYMERS

COMPANY	TECHNOLOGY
Pervasis Therapeutics (Cambridge, MA)	Polymers combined with drugs and/or cells to treat cardiovascular disease
GMP Companies (Fort Lauderdale, FL)	Polymers and cell therapies for neural repair, with technologies licensed from the Burnham Institute in La Jolla, CA, and other academic centers


Dots of polymer material support stem-cell growth. Large dots are magnified stem cells growing on polymer and have been digitally superimposed.

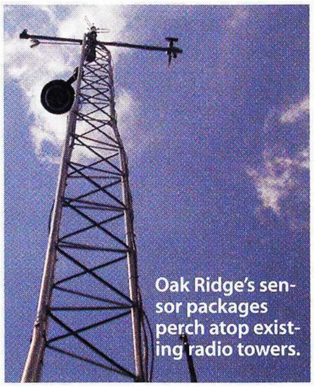
HOMELAND SECURITY

Terror Net

Ever since the September 11 terrorist attacks, federal agencies have been wishing for a system capable of issuing a nationwide alert at the first sign of a chemical, biological, or radiological attack. Now such a system is undergoing trials in Tennessee.

Developed by the U.S. Department of Energy's Oak Ridge National Laboratory in Tennessee, the new system consists of sensor packages attached to structures such as cell-phone towers. The packages will include detectors for airborne chemicals and radioisotopes, and for weather changes. The intent of the system—which is being tested in Knoxville, Nashville, and other locations—is to detect plumes of contaminants, predict their spread, and quickly alert command centers. In a 2002 test, prototype sensors successfully detected discharges of simulated sarin gas in three cities 140 to 270 kilometers apart and dispatched pertinent data in less than two minutes. The current trial will test the system on an even larger scale.

The Department of Defense, the Department of Homeland Security, and other organizations are sharing the cost of developing the system; at least $12 million has been assigned to it for the coming year. "At this point, we are not deployed nationwide, but we've demonstrated the scalability of the technology," says Jim Kulesz, special-projects manager at Oak Ridge. Observers say the technology, while promising, is not a panacea. If fully deployed, says Paul Sereiko, president of Needham, MA-based wireless-sensor maker Sensicast Systems, it "will provide an excellent early-warning system for wide-area contaminant monitoring." But, he adds, additional local monitoring will still be needed. Lakshmi Sandhana


Oak Ridge's sensor packages perch atop existing radio towers.

COURTESY OF OAK RIDGE NATIONAL LABORATORY (TERROR NET); COURTESY OF DANIEL ANDERSON, MIT (SCAFFOLDS)

ENERGY

Plasma Power

Cathode-ray-tube TVs, with their familiar protruding backsides, may look bulky and primitive next to today's sleek flat-screen models, but they've still got two big advantages: they're cheap, and they're relatively energy efficient. Plasma flat screens, for example, still cost $2,000 or more apiece, and they use up to five times as much electricity as CRTs. They're such energy hogs, in fact, that global adoption of plasma TVs could increase electrical demand noticeably, increasing both the chances of blackouts and the volume of greenhouse gases emitted by power plants.

At the very least, plasma screens are sure to put additional stress on the electrical grid, which has lately approached its breaking point in states such as California. A typical plasma display consumes about 1,000 kilowatt-hours of power annually, compared to approximately 233 kilowatt-hours for an average CRT, according to a study by the United Kingdom's Department of Environment, Food, and Rural Affairs. And in ten years, it is widely believed, half of all TVs will be flat-panel displays, although it's unclear whether plasma, liquid-crystal displays, or newer technologies will predominate.

If plasma wins, the consequences could be startling. If half of California's 12.7 million households replaced their CRTs with plasma displays, the state's electrical usage would grow by 7.6 billion kilowatt-hours annually, an increase of about 1.3 percent. Supply-and-demand projections from California's state energy commission show that during hot summers, the extra demand from these plasma screens alone could eat up much of the state's reserve generating capacity, increasing the likelihood of rolling blackouts. A solution might be for the state to ask citizens to turn off their televisions in hot weather—but such measures are unlikely to be received well in the homeland of the world's entertainment industry.

Charles C. Mann

"Cyber rodents" circle around digital treats in Kenji Doya's Okinawa, Japan, lab.

COURTESY OF KENJI DOYA (RODENT)

ROBOTICS

I, Rodent

At the Okinawa Institute of Science and Technology in Japan, neurobiologist Kenji Doya is ankle-deep in rodents. Not real ones, but "cyber rodents" made of plastic and silicon. Two of the critters circle each other in a mating dance. Others forage for fresh batteries on the floor. Another one just sits there. "That one is lazy," says Doya, who also heads a group at the Advanced Telecommunications Research Institute in Kyoto. "It doesn't expend energy to get a reward"—and probably won't last long.

Groups of robots have been fixtures in academic robotics labs for years. But Doya's project is one of the first to use robots to probe how administering rewards to individuals when they achieve simple goals can give rise to intelligent group behaviors. This work could help designers build machines that collaborate to carry out complex tasks. By studying how groups of mobile robots interact and adapt, researchers could eventually develop self-sufficient swarms of robots that explore hostile environments, gather surveillance data, and repair equipment remotely.

The key, says Doya, is teaching the robots to do the right thing. Each 22-centimeter-long cyber rodent is equipped with a processor chip, a camera, sensors, motorized wheels, and infrared data ports that allow it to communicate, or "mate," with others. If a robo rat approaches a battery pack or orients itself to mate, it receives a digital "reward"—a snippet of software code that reinforces that behavior in the future. Over time, says Doya, the robots compete for power and may even develop territories and alliances.

"It's early-stage but very promising," says Terry Sejnowski, a computational neuroscientist at the Salk Institute for Biological Studies in La Jolla, CA. "Kenji's robots have a clever algorithm to develop sophisticated behaviors."

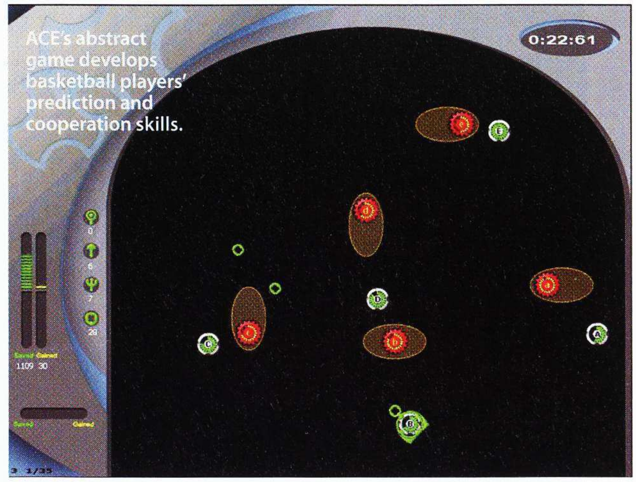
It could be years before such robots do useful work outside the lab. But Junku Yuh, program director of robotics and computer vision at the National Science Foundation, says funding multirobot systems is important because they could lead to more efficient ways to control machines and gather information in the field. To that end, researchers at the University of Pennsylvania, the Georgia Institute of Technology, and Burlington, MA–based iRobot are developing new theories about and military applications for swarms of robots. There is safety in numbers—but there could also be smarts. **Gregory T. Huang**

SPORTS

A Gym for the Brain

Great basketball players aren't just powerful athletes: they also have a "sense" of the entire court and the ability to make split-second decisions, which many people assume are innate. But a company in Netanya, Israel, called Applied Cognitive Engineering (ACE) believes that these talents can be taught—and to prove it, it has created a video-game-like tool, based on training techniques used by the Israeli Air Force, that helps players learn when to shoot or pass the ball and how to work with teammates.

ACE's program, called IntelliGym, bears no external resemblance to basketball. The player initially shoots down enemy spacecraft using the keyboard's arrow keys. Over the span of a dozen or so 40-minute sessions, the tasks get more complicated, challenging the player to confront a variety of enemies with a range of weapons. That may sound like standard video-game fare, but there's a carefully planned strategy underneath: each level is designed to exercise specific skills used in basketball, such as predicting an opponent's trajectory, deciding when to shoot at an opponent who keeps changing direction, and working with other team members to defeat a number of opponents. Reports of player and team performance are automatically generated for review by coaches.



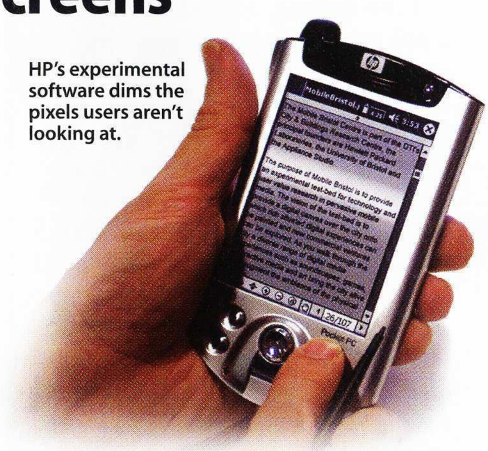
ACE's abstract game develops basketball players' prediction and cooperation skills.

Daniel Gopher, a professor of industrial engineering at the Technion-Israel Institute of Technology who introduced a computer-based trainer to the Israeli Air Force more than a decade ago and found that it improved pilots' skills by up to 30 percent, agreed to help ACE design a new tool aimed at the sports industry, where improved performance can mean big bucks. "We spend so much time in the weight room working on the physical aspect, but this is the one area that is pretty untapped—the cognitive and mental aspects of the game," says Ed Schilling, assistant coach for the University of Memphis Tigers, one of two NCAA Division I teams that have already signed contracts with ACE. **Tania Hershman**

COMPUTING

Energy-Saving Screens

Processors and memory chips keep growing in capacity, but batteries don't improve fast enough to keep up. So the only way to increase the battery life of mobile devices such as PDAs and smart phones is to reduce the amount of power they consume. Working with a new generation of displays based on organic light-emitting diodes (OLEDs), researchers at Hewlett-Packard have found a way to do that: dimming the parts of the screen that aren't in use.



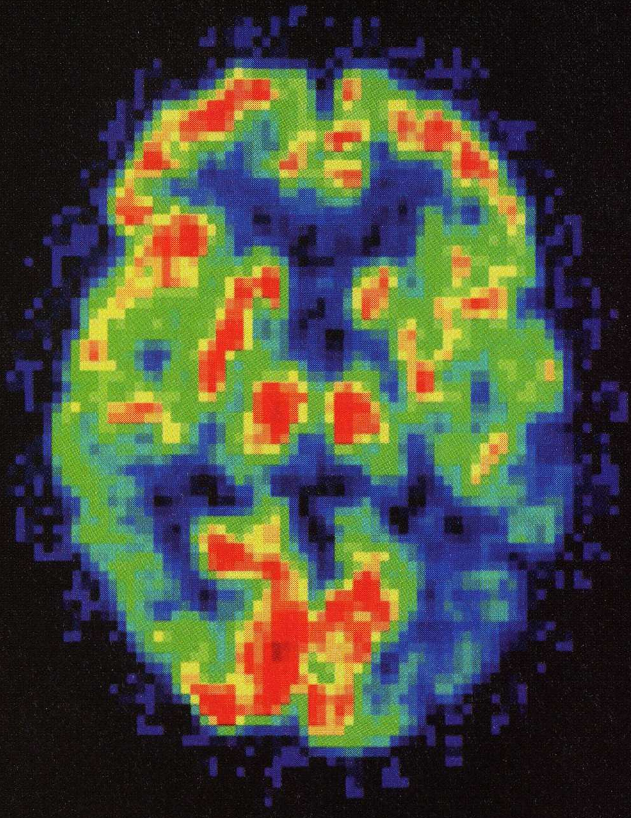
HP's experimental software dims the pixels users aren't looking at.

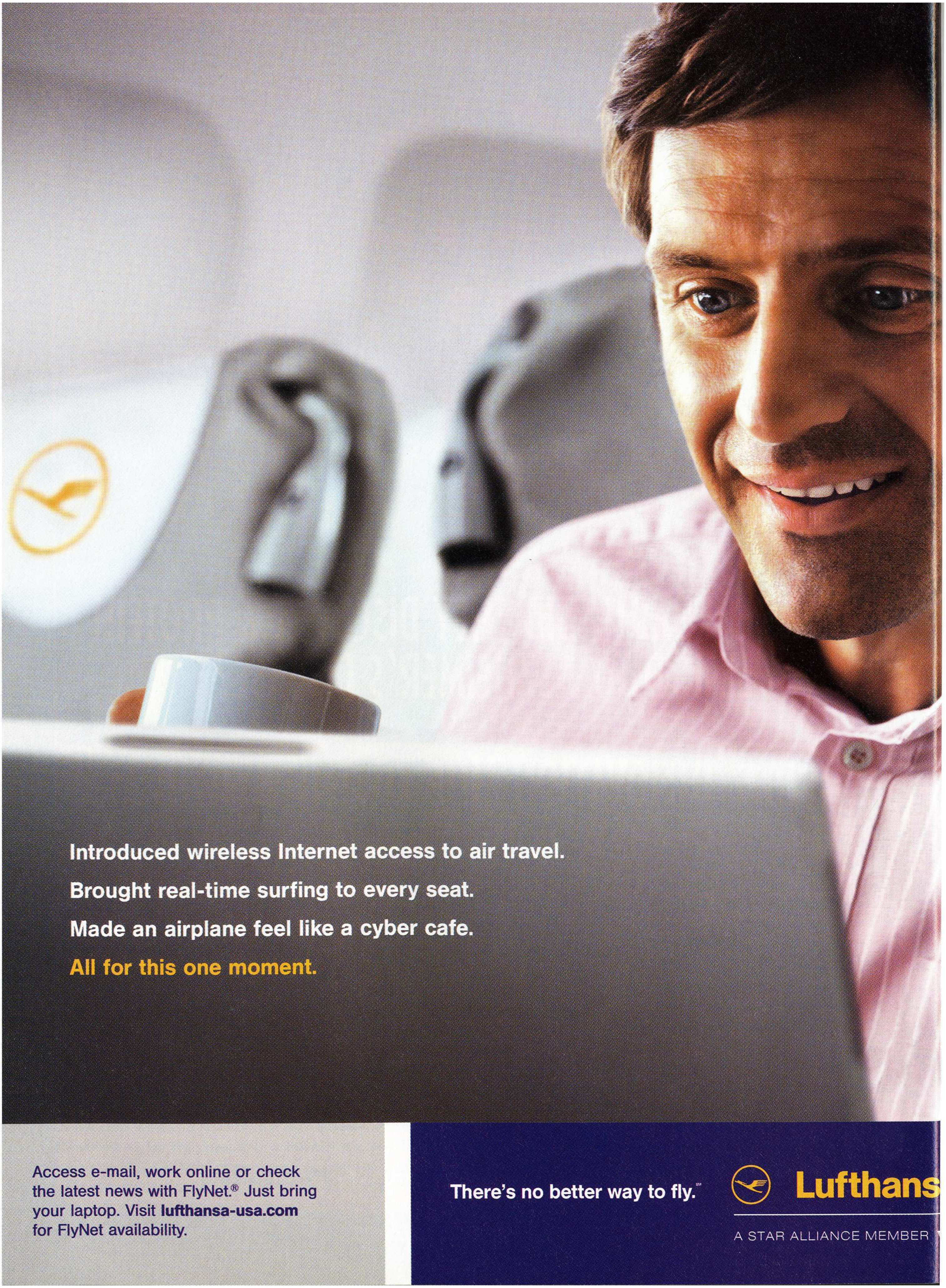
"We have energy-aware central processors; why don't we have energy-aware interfaces?" asks Parthasarathy Ranganathan, a senior research scientist at HP Labs. The prevailing approach to energy-saving displays—leaving the entire screen illuminated while a device is active but turning it off after a minute or two of inactivity—is less than ideal, since it uses a lot of energy when the screen's on and, when it's off, forces the user to push a button to return to his or her task. Instead, Ranganathan's team developed special software that monitors a PDA's screen when it's in use and automatically dims the unimportant pixels—for example, everything in the background behind an active pop-up menu or dialogue box.

In studies with human volunteers, Ranganathan's team found that Pocket PC devices equipped with the energy-saving software could last 1.3 to 8 times longer on a single charge than those without the software. Not only that, but "95 percent of our users preferred the new interfaces, even without the energy advantages," Ranganathan says. "Deemphasizing low-interest areas means you're emphasizing high-interest areas"—which seemed to help users focus on their immediate tasks.

The method is not effective with most of today's standard liquid-crystal displays, which are illuminated by fluorescent bulbs that remain on even if a particular group of pixels is dark. But in OLED screens, each pixel emits its own light, so "if you turn off a pixel, you don't have to spend power on it," explains Ranganathan. Since phones and PDAs with OLED screens are expected to become commonplace within two years, the new software could soon be a standard feature of the operating systems of mobile devices. **Wade Roush**

COURTESY OF HEWLETT-PACKARD (SCREENS); COURTESY OF APPLIED COGNITIVE ENGINEERING (GYM)

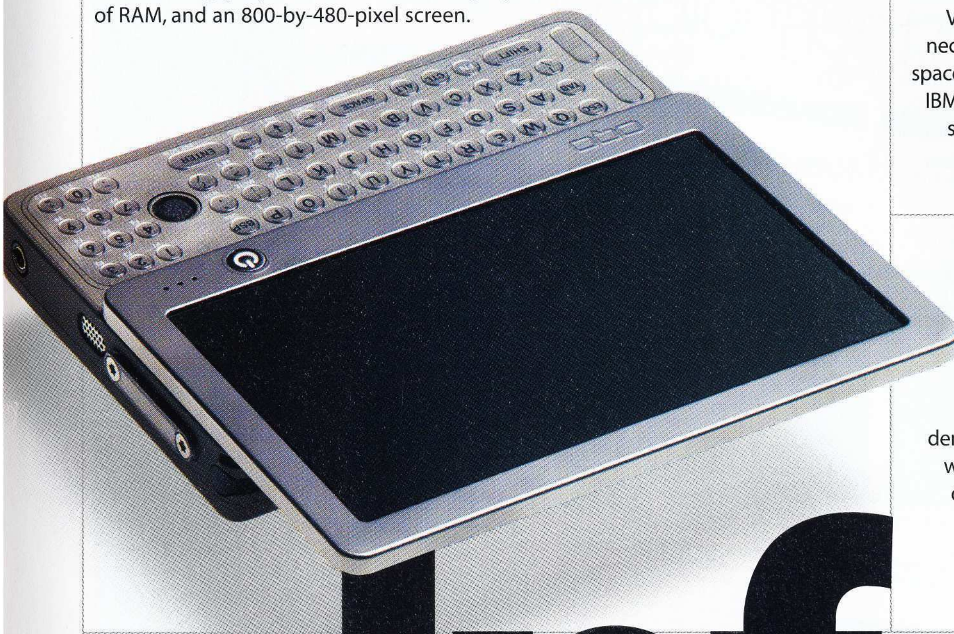




Introduced wireless Internet access to air travel.
Brought real-time surfing to every seat.
Made an airplane feel like a cyber cafe.
All for this one moment.
Access e-mail, work online or check the latest news with FlyNet.® Just bring your laptop. Visit lufthansa-usa.com for FlyNet availability.
There's no better way to fly.
Lufthans
A STAR ALLIANCE MEMBER

gadget

San Francisco-based **Oqo** started taking orders for its "handtop," the world's smallest fully functional Windows XP computer, in October. About 13 centimeters by 9 centimeters by 2 centimeters in size, the device has a pop-out thumb keyboard, a 20-gigabyte hard drive, 256 megabytes of RAM, and an 800-by-480-pixel screen.



breakthrough

Once the dominant purveyor of servers for storing huge corporate databases, **IBM** has gradually been edged out by Hopkinton, MA-based **EMC**. But Big Blue has now struck back, introducing a device that squeezes all the data stored in a refrigerator-sized EMC server—about 1.2 terabytes—into a box a little larger than a VCR, for about half the cost. Key to cramming all the necessary disk drives and electronics into such a small space were advanced cooling techniques adapted from IBM's blade servers. The boxes can be combined into a system holding as many as 67.2 terabytes, twice the amount of data in the U.S. Library of Congress.

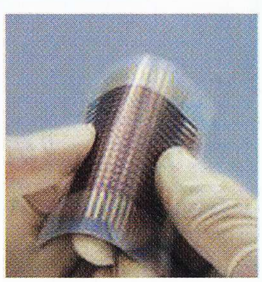
alliance

TiVo and **Netflix**—two companies giving the television networks fits by providing more alternatives to live-broadcast or cable TV—have announced a plan to jointly offer movies-on-demand via the Internet. Starting in 2005, TiVo owners with broadband Internet connections will be able to download movies directly from Netflix's vast library, rather than waiting to receive DVDs in the mail.

Infote

debut

Microsoft has unveiled a music download site called **MSN Music**, an answer to Apple's phenomenally successful iTunes online music store. As at iTunes, songs are $.99 each. The biggest difference: the tunes at MSN Music are in Windows Media format, meaning they'll play only on PCs or portable media players designed for Microsoft's format—not on iPods.



«advance

Even the most dexterous robots still lack a sense of touch, which could be critical when they're repairing other machines, preparing food, or caring for humans in, say, hospitals or senior centers. Now researchers at the **University of Tokyo** have devised a pressure-sensitive array of transistors on a flexible plastic that could be wrapped around a robot's fingers, forming a kind of skin. Lead researcher Takao Someya says the material could be ready for practical use by 2008.

deployment

Lost your hotel key card? No problem: an eyeball will do. Boston luxury lodge **Nine Zero** has become the world's first hotel to restrict room access using iris-scanning technology. Guests in the hotel's exclusive Cloud Nine suite have their irises photographed when they arrive, then peer into a reader outside the suite to unlock the door. The same technology is being tested at Boston's Logan Airport and other airports as a way to speed travelers through security lines.

COURTESY OF THE UNIVERSITY OF TOKYO (ADVANCE); COURTESY OF OQO (GADGET)

INSTITUTION	AWARD (IN MILLIONS)
Northeastern University	$12.4
Ohio State University	$12.9
Stanford University	$7.5
University of California, Berkeley	$11.9
University of Pennsylvania	$11.4
University of Wisconsin-Madison	$13.4

funding

The **National Science Foundation** has awarded $69 million to six universities for the establishment of new nanotech centers around the country. All told, the NSF is providing $250 million in grants for nanoscale research in fiscal year 2004.

milestone

Researchers at **Sandia National Laboratories** in Albuquerque, NM, say they have made a motion detector that is a thousand times more sensitive than the most sensitive existing one. The micromechanical device, which has features as small as 100 nanometers across, uses two microscopic, comblike structures to diffract light from a laser beam; even a minute disturbance of the upper comb, which is secured by springs, measurably alters the light.

Nanot

advance

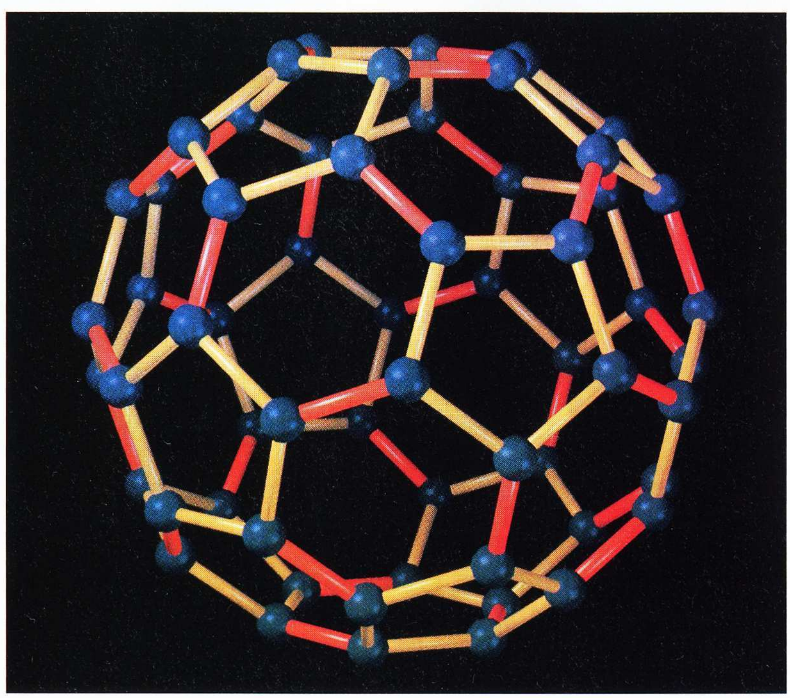
Ultrasensitive detection of viruses could mean more effective tools for diagnosing diseases and warning of bioterrorism attacks. Now researchers at **Harvard University** have achieved the ultimate in sensitivity: the detection of individual viral particles. The group's sensor uses nanowires and can electrically detect the presence of a single virus in real time. The Harvard chemists hope to build devices capable of detecting a wide variety of viral threats with the same sensitivity by using a series of nanowires.

centers

The National Institutes of Health have awarded $10 million to **Emory University** and the **Georgia Institute of Technology** to establish a cancer nanotechnology research program. The goal is to develop a new class of nanoparticles for molecular and cellular imaging, with a primary focus on improving the detection and treatment of prostate cancer.

safety

Amidst worries about the possible health dangers of nanomaterials, researchers at Rice University's **Center for Biological and Environmental Nanotechnology** have found a way to alter the toxicity of buckyballs, large soccer-ball-shaped carbon molecules that are among nanotech's most promising materials. The researchers report that changes to the surfaces of the buckyballs modify their toxic effects on cells. The executive director of the lab, Kevin Ausman, says the preliminary studies indicate that buckyballs should be "studied in more detail."



research

Scientists have become quite skilled at determining the structures of stable molecules, but measuring the rapid changes that molecules undergo during chemical reactions is a different matter entirely. **State University of New York at Buffalo** researchers now report experimental structural measurement of molecules in high-energy states that persist for just millionths of a second.

J. BERNHOLC ET AL., NCSU/PHOTO RESEARCHERS, INC.

NEW

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follow-up

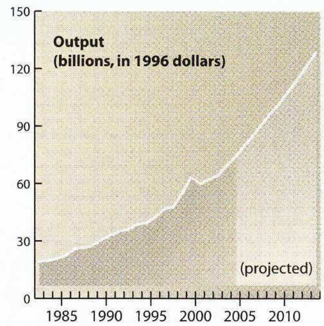
Iceland's **deCode Genetics** has won a five-year, $23.9 million contract from the U.S. National Institute of Allergy and Infectious Diseases; under it, deCode will scan the genomes of Icelandic volunteers to find genes involved in susceptibility to tuberculosis, influenza, and other infections and associated with adverse reactions to the smallpox vaccine. DeCode has already used its population-based approach to find genes involved in heart disease and other ailments *(see "Translating Iceland's Genes into Medicine,"* TR *September 2004).*

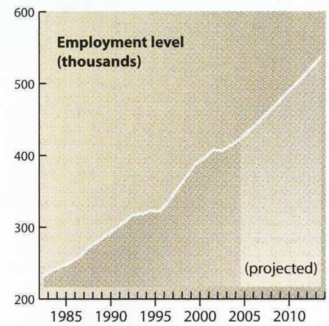
financing

Biodefense startup **PharmaAthene** of Annapolis, MD, has raised $50 million in a new round of financing. The company plans to use the money in part to develop an anthrax-toxin-blocking drug discovered by Harvard Medical School researchers.

metric

In 2014, the **U.S. biopharmaceutical industry** will employ more than half a million people and generate more than $120 billion in goods and services, according to forecasts from the nonprofit Milken Institute.





Biote

milestone

An international consortium has sequenced the 480-million-plus DNA letters of the *Populus* genome—making it the first tree genome to be completely sequenced. Consortium researchers, from organizations including the **U.S. Department of Energy**, **Genome Canada**, and the **Umeå Plant Science Centre** in Sweden, have found more than 40,000 genes in a preliminary analysis of the sequence.

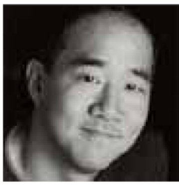
patent

Menlo Park, CA's **Geron** has won what could be a key piece of stem-cell intellectual property: a patent on a technique that allows human embryonic stem cells to be cultured in the lab without the additional cells that are normally used to help them grow. Eliminating the extra cells, the company argues, will make it easier to scale up commercial stem cell production and will reduce the chances of contamination with infectious agents.

ipo

IntraLase of Irvine, CA, raised $86 million in its initial public offering this October. The company, now listed on the Nasdaq National Market, makes laser-based devices for the popular vision correction surgery Lasik.

Showing Up



THIS PAST YEAR, I'VE HAD THE GREAT PRIVILEGE of writing about five entrepreneurs. I interviewed each of them at a critical moment in the life of his or her startup—rather easy to do, actually, as practically every moment in a seed-stage venture is critical. In this, my final column, I'm returning to them to see how their decisions shine in hindsight's glare. Much to my delight, not only do all five companies still exist, but their founders report that they are thriving. Such assurances may, in part, reflect the necessarily optimistic outlook shared by all those who start companies. But as my old business partner, Jeet Singh, used to say, half of winning the battle is showing up to the fight.

Bill Zebuhr, founder of **Ovation Products**, fervently believes that millions of kilometers of water mains and sewer pipes will someday be replaced by his Clean Water Appliances, humming away in basements—and in remote villages that now lack clean water—and efficiently transforming wastewater into pure drinkable water. When I wrote about Ovation last December, Zebuhr had exactly one "alpha" unit working and was trying to raise the necessary financing for the next version.

Fortunately, Zebuhr was able to close on $1.4 million in angel investment, which allowed him to create a "beta" model that boosted output from 45 to 75 liters of clean water per hour and dropped production costs from the $50,000 range down to less than $10,000. Now he's back out on the fund-raising trail, this time hoping to raise four or five million—enough to tool up for real production.

When I spoke to the founder of **SwapitShop**, Jonathan Attwood, for the March issue, his plan to create a universal currency for children was in danger of failing to reach a critical mass of recognition and credibility. Product manufacturers use Attwood's "Swapits," which are redeemable for toys and other goodies on SwapitShop's eBay-like website, as incentives for children to buy their goods. But without enough children demanding Swapits or enough manufacturers buying and distributing them, the currency and company could slip into fatal obscurity.

Attwood happily reports that he's increased Swapit sales to the point where the company is profitable and he is planning to double his staff. "Last year, if someone offered us £100 to sweep the street, we'd have taken it," laughs Attwood. "Now we can finally start thinking about how to strategically grow our business."

In my May column about **Minerva Biotechnologies**, I wrote that while the company's gold nanoparticle–based biosensor technology may have dozens of potential applications and markets, founder Cynthia Bamdad was probably best off focusing on one without distraction. Bamdad reports that MUC1 cancers, a group she's been studying that includes most breast and prostate cancers, have taken that front-and-center role for Minerva—and that the company is at a "make or break" moment. Some major pharmaceutical companies are developing the same class of drug molecules that Bamdad independently discovered, but without Minerva's biosensor technology, they are operating without knowledge of the underlying mechanism.

At the same time, Bamdad's facing a potential money problem. "Angels who were willing to put money down on a song and a prayer are suddenly spooked by real results that indicate a real working cure!" she complains. Biotech venture capital firms are ready to invest, but only on terms that Bamdad finds painful. Fortunately, a group of angel investors who read about Minerva in *Technology Review* sounds quite serious about closing a deal, which should enable Bamdad to navigate the complex partnerships and intellectual-property negotiations required to take Minerva to the next stage.

Maggie Orth's life's work is literally weaving technology into our world. When I spoke to her in July, the founder of **International Fashion Machines** and pioneer of "interactive textiles" (imagine, say, a computer keypad embroidered directly onto a shirtsleeve) was trying to launch a line of woven touch-fabric light switches. She's since discovered that getting the products certified as safe is a more lengthy process than she imagined, not because they are dangerous, but because existing safety standards were written for an age when textiles and electricity never mixed. Interest in her fabrics is growing, however, and she's receiving a stream of unsolicited requests from clothing manufacturers to help develop new concepts.

When I wrote about **Atomate** a scant two months ago, its founder Brian Lim felt he'd found the perfect niche market: creating nanotech research tools rather than developing his own nanotech devices, or as he puts it, "selling the pans to the prospectors." So I was doubly astonished to find Lim practically hollering "Eureka" down the phone as he explained that his scientists may have struck their own "diamond mine"; they've discovered a new kind of nanowire that Lim hopes will boost silicon chips' processing speed by "orders of magnitude." Lim is already thinking ahead, toward Atomate's transformation into an outright nanotech prospecting operation.

I suspect that Atomate's discoveries were far from accidental and were spurred by an inherent entrepreneurial dissatisfaction with watching someone else working out on the cutting edge. I must confess that while I've hugely enjoyed writing this column, it has also been a constant and frustrating reminder of how much fun building a company can be. Now I am thrilled to report that I am trading my word processor back in for my programming editor and rejoining the entrepreneurial ranks. In true startup tradition, my new company will be in "stealth mode" for the foreseeable future. But perhaps someday I'll again have the honor to be in the pages of *Technology Review*. TR

Joe Chung cofounded Cambridge, MA-based Art Technology Group.

A NEW VISION FOR NUCLEAR WASTE

THE YUCCA MOUNTAIN NUCLEAR-WASTE REPOSITORY IS STALLED AND MAY NEVER OPEN. IT'S TIME TO ADOPT A SURER, SHORT-TERM PLAN FOR STORING HIGHLY RADIOACTIVE MATERIAL—AND BET THAT OUR GRANDCHILDREN WILL FIND BETTER THINGS TO DO WITH IT.

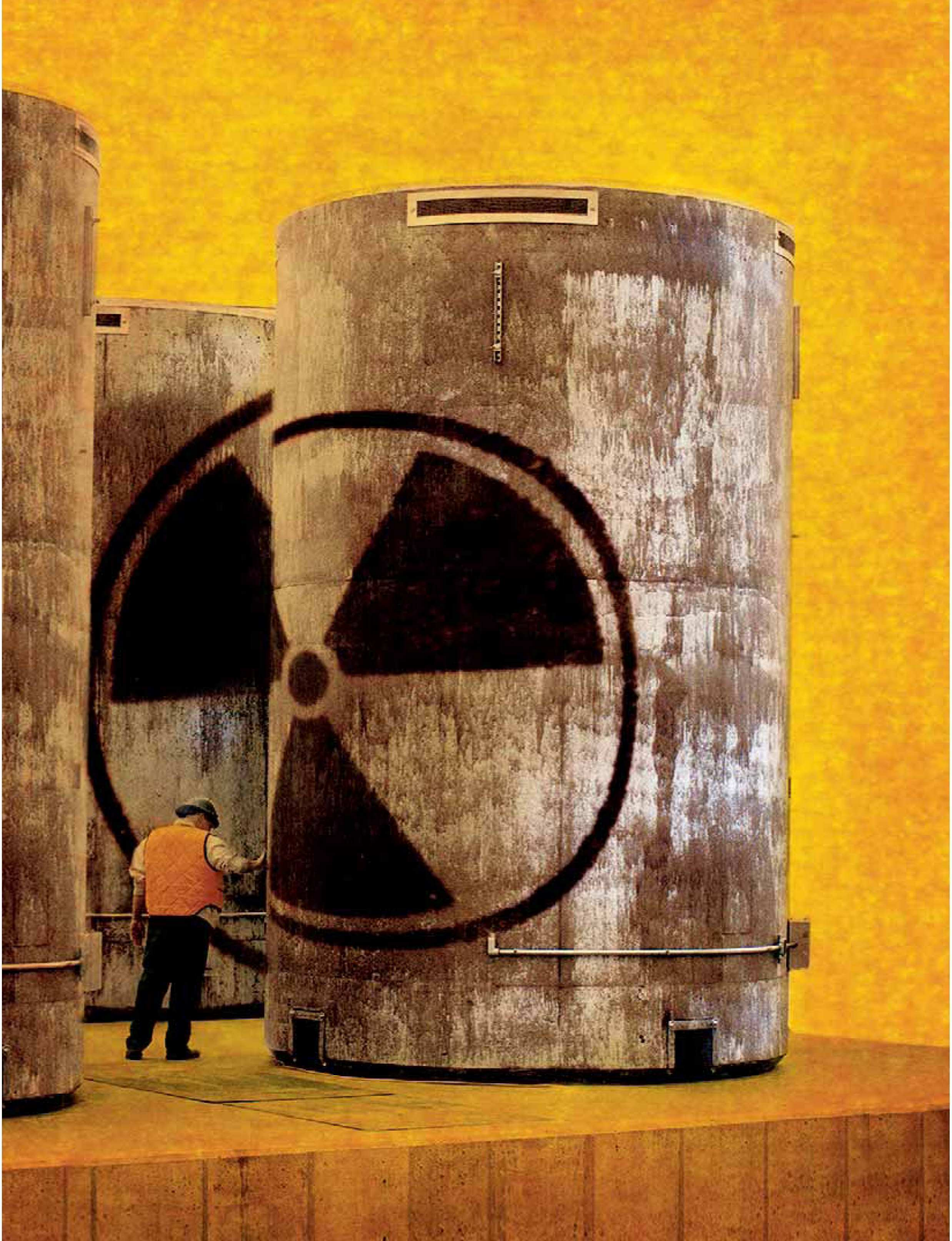
BY MATTHEW L. WALD

WHEN AMERICAN AIRLINES FLIGHT 11 flew at low altitude down the Hudson River valley on the morning of Sept. 11, 2001, its target was the north tower of the World Trade Center. But its impact is still being felt at a cluster of buildings it passed about five minutes before it reached lower Manhattan, at a nuclear-reactor complex called Indian Point in Buchanan, NY. Adjacent to the site's two operating reactors are two buildings packed with highly radioactive spent-fuel rods, in pools of water 12 meters deep and tinged Ty-D-Bol blue by boron added to tamp down nuclear chain reactions. The soothing hum of the pumps that circulate the building's warm, moist air—and, critically, keep the water cool—lends an atmosphere of industrial tranquility.

Without that cooling water, the fuel cladding might overheat, melt, catch fire, and release radiation. Whether the impact of a Boeing 767 like Flight 11 could drain one of the pools and disable backup water pumps, starting such a fire, is far from clear. Nevertheless, the threat of terrorism in general and the flyover of Flight 11 in particular have reignited the debate about why all of this dangerous fuel is still here—indeed, why all spent fuel produced at Indian Point in three decades is still here—and not at Yucca Mountain, the federal government's burial spot near Las Vegas, where it was supposed to be shipped beginning six years ago.

Late this past summer, a construction project began at Indian Point that will allow the fuel to be pulled out of the pools. But it's not going to Yucca. The government says Yucca won't be ready until 2010. Executives in the nuclear industry say a more likely date is between 2015 and never. So instead of traveling to Nevada, Indian Point's fuel is traveling about 100 meters, to a bluff overlooking the Hudson River. On a late-summer day this

PHOTOILLUSTRATION: STEPHEN WEBSTER; PHOTOGRAPH: DAVID MURRAY



year, a backhoe tore out maple and black-walnut trees to make way for a concrete pad. Beginning next year, the first of a planned 72 six-meter-tall concrete-and-steel casks will be placed there, a configuration that adds storage capacity and thus allows the twin power plants to keep operating. Though they provide a hedge against a worst-case fuel-pool meltdown, these casks are merely another temporary solution. The fact that they're needed at all represents the colossal failure of the U.S. Department of Energy's Yucca plans and technology.

Yet as engineering and policy failures go, this one has a silver lining. Conventional thinking holds that Yucca's problems must be solved quickly so that nuclear waste can be squirreled away safely and permanently, deep within a remote mountain. But here's the twist: with nuclear waste, procrastination may actually pay. The construction of cask fields presents a chance to rethink the conventional. The passage of several decades while the waste sits in casks could be immensely helpful. A century would give the United States time to observe progress on waste storage in other countries. In the meantime, natural radioactive decay would make the waste cooler and thus easier to deal with. What's more, technological advances over the next century might yield better long-term storage methods. "If it goes on for another 50 years, it doesn't matter. It could go on for 100 or 200 years, and it's probably for the better," says Allison Macfarlane, a geologist at MIT and coeditor of a forthcoming book on Yucca. "We've got plenty of time to play with it."

The government must now accept that its Yucca plan is a failure and that casks are the de facto solution. Indian Point's cask pad will not be the first; about two dozen operating reactors have them already. Others are likely to soon join the list. And some casks—at Rowe, MA, Wiscasset, ME, Charlevoix, MI, and a site near Sacramento, CA—are nuclear orphans, having outlived their reactors. Each cask pad is roughly the size of a football field, floodlit, watched by motion sensors and closed-circuit TV, and surrounded by razor wire and armed guards. Given the homeland-security concern posed by nuclear-waste facilities, and the need to guard them individually, do we really want 60 of them—serving all 125 commercial reactors that have ever operated—to rise around the nation, many near population centers? If casks are the solution for the next generation or two, they should be put in one place.

Yucca is already on tenuous ground; in July a federal appeals court said that to open the mountain burial site, the government would have to show that it could contain waste for hundreds of thousands of years. Extensive scientific analyses by the Energy Department show it cannot. The court's decision throws the whole question back to the U.S. Congress, which must now decide whether to proceed with Yucca at all. This presents an opportunity to align policy with physics and abandon the Yucca-or-bust dogma that has dominated the debate for nearly 20 years. Casks, centrally located, could make the high-level-waste problem a lot easier to solve and increase national security much sooner, too.

WE DON'T REALLY NEED A 100,000-YEAR BURIAL SOLUTION FOR NUCLEAR WASTE. A MERE 100 YEARS IN OUTDOOR CASKS WILL DO FINE. THE WASTE WILL BECOME EASIER TO MANAGE—EVEN USEFUL—AND STORAGE TECHNOLOGIES WILL IMPROVE. BUT THE CASKS SHOULD BE PUT IN ONE PLACE.

THE TUNNEL VISION

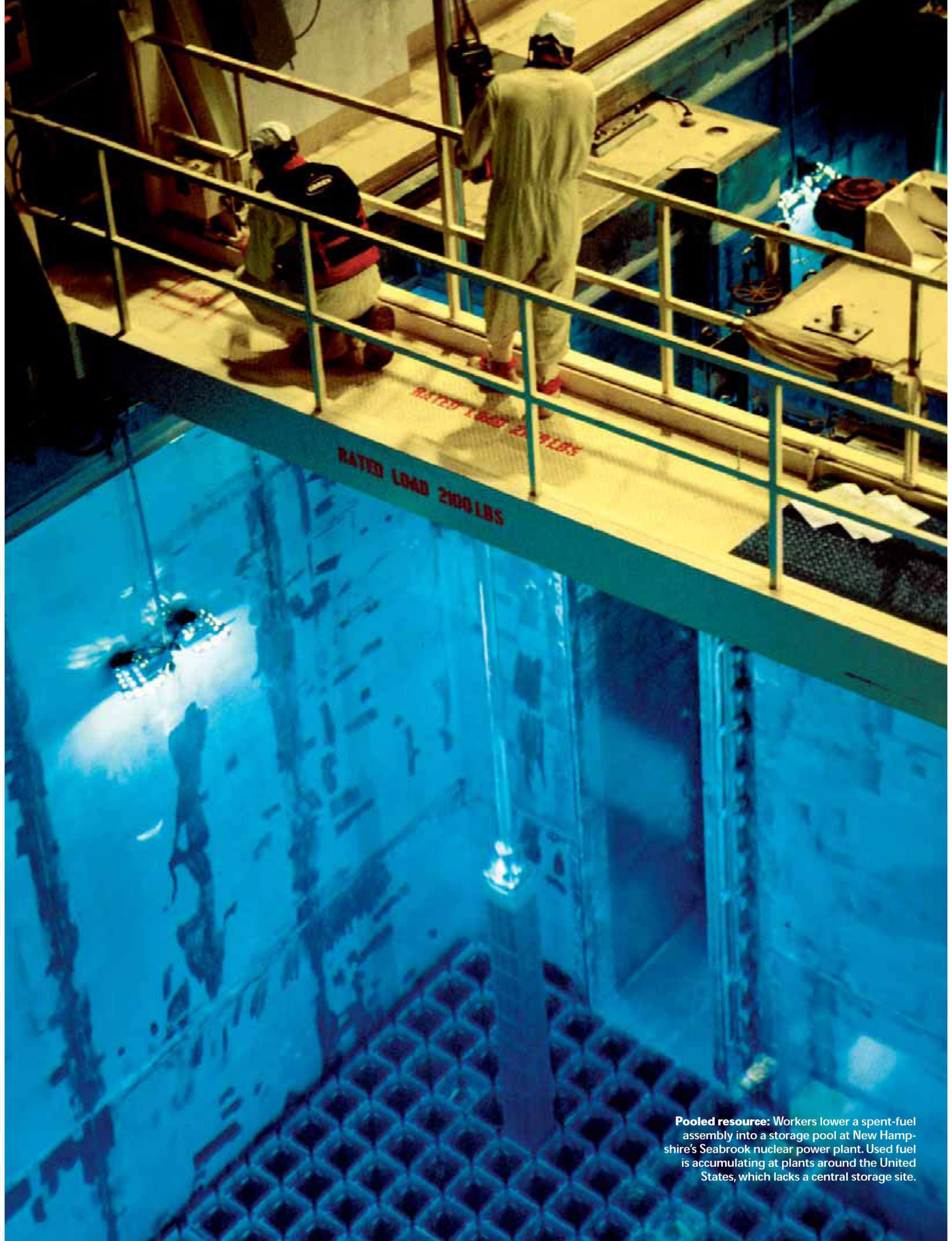
The federal fixation on Yucca Mountain now spans two decades. Beginning in the early 1980s, the government agreed to take waste from any nuclear utility that paid a tariff of a tenth of a cent per kilowatt-hour generated by its reactors. All the companies quickly signed up. But the selection of Yucca, 150 kilometers northwest of Las Vegas, was never driven by science. The site was chosen by that august group of geologists and physicists, the U.S. Congress. So far, the Energy Department has spent about $6 billion on development, including building an eight-kilometer, U-shaped tunnel through the mountain, in some places nearly 300 meters below the surface. It plans to spend at least $50 billion more to build dozens of side tunnels, package the waste in steel containers that look like the tanker portion of a gasoline truck, place the waste in the tunnels, and operate the site for 50 to 100 years before sealing it for eternity.

Problems have plagued Yucca since the beginning. In Senate debate, proponents stressed how dry it is. Yucca is, in fact, located in what is now a desert. But it turns out that the ground is moist. Even the 19 or so centimeters of rain the mountain gets each year is a major problem. Over time, moisture can corrode even the best alloys known to man. Corrosion would mean that rainwater percolating through the ground could carry radioactive materials with it and convey them to irrigation systems and drinking-water wells in the region, delivering substantial doses of radiation to unsuspecting people generations hence.

Heat is another problem. The shorter-lived radioactive isotopes in used fuel, principally cesium-137 and strontium-90, give a single fuel assembly, fresh out of the reactor, a heat output equal to that of about 20 handheld hair dryers. That's why each power plant has an adjacent storage pool that circulates cooling water. Once the fuel was underground at Yucca, it would be hot enough to boil ground water into steam. Steam could corrode the containers or break up surrounding rock, raising uncertainty about secure burial. Spreading the waste out would dissipate the heat, but it would also greatly reduce Yucca's storage capacity. Then there's the problem of radioactive decay. High-energy particles can interact with surrounding materials, breaking them down or causing them to give off hydrogen, a gas that can explode or burn.

Early this year, researchers at Catholic University of America, hired by the state of Nevada, took samples of the kind of metal the Energy Department wants to use at Yucca and put them in some water mixed with the minerals present in the mountain. As a series of speakers lectured reporters on why Yucca was a bad idea, the researchers sautéed the metal over a burner. By the time

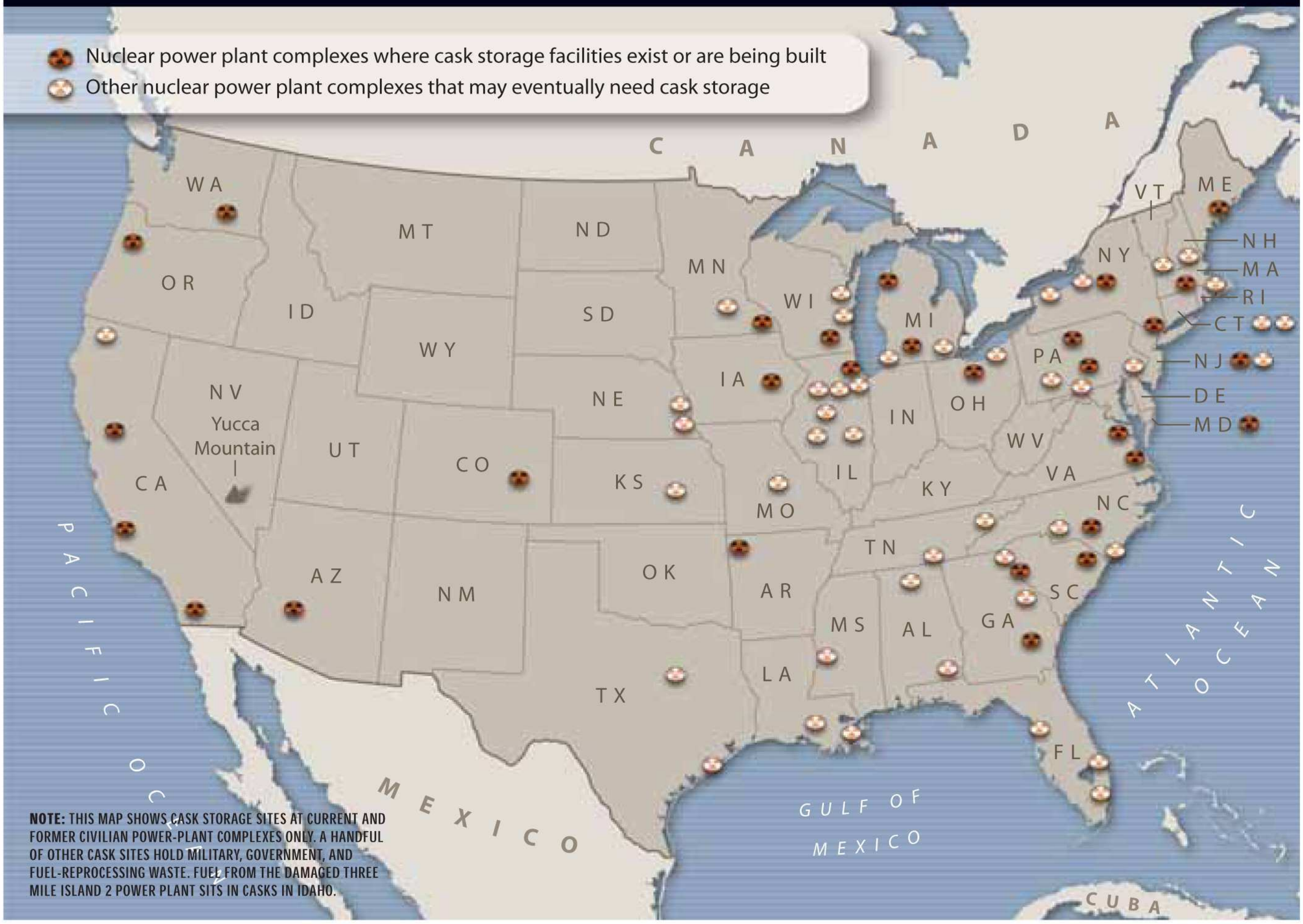
TOMMY THOMPSON



Pooled resource: Workers lower a spent-fuel assembly into a storage pool at New Hampshire's Seabrook nuclear power plant. Used fuel is accumulating at plants around the United States, which lacks a central storage site.

DOZENS OF YUCCA MOUNTAINS

A GROWING NUMBER OF NUCLEAR POWER PLANT COMPLEXES ARE BUILDING OUTDOOR FACILITIES TO STORE THEIR HIGHLY RADIOACTIVE SPENT FUEL IN CONCRETE CASKS. WITH THE GOVERNMENT'S YUCCA MOUNTAIN WASTE REPOSITORY STALLED, THESE SCATTERED CASK SITES REPRESENT THE NATION'S DE FACTO LONG-TERM SOLUTION.



the lectures were done, the samples had corroded, some of them all the way through. How faithfully the stunt reproduced the chemistry of Yucca Mountain is debatable. But clearly, Yucca is subject to serious doubts. "You have to think somewhere back in the premise structure of the whole thing, something was dreadfully wrong," says Stewart Brand, a San Francisco–based consultant who once advised the Canadian government on what to do with its own waste.

COOLER FUEL

The argument against casks is that they are merely temporary, not meant to serve longer than perhaps 100 years, and that they are a kind of surrender, leaving this generation's waste problem to a future generation to solve. Yet their impermanence is exactly what's good about them. A century hence, spent reactor fuel will be cooler and more amenable to permanent disposal. In fact, within a few decades, the average fuel bundle's heat output will be down to two or three hair dryers. After 150 years, only one-thirty-second of the cesium and strontium will remain. The remaining material can be buried closer together without boiling underground water. Reduced heat means reduced uncertainty.

Granted, spent fuel will be far from safe after such a relatively short period. Even after 100 years, it will still be so radioactive that a few minutes of direct exposure will be lethal. "It's many, many, many thousands of years before it's a no nevermind," says Geoffrey Schwartz, the cask manager for Indian Point, which is owned by Entergy Nuclear. "But the spent fuel does become more benign as time goes by."

The fuel could be more valuable, too. For decades, industry and government officials have recognized that "spent" reactor fuel contains a large amount of unused uranium, as well as another very good reactor fuel, plutonium, which is produced as a by-product of running the reactor. Both can be readily extracted, although right now the price of new uranium is so low, and the cost of extraction so high, that reprocessing spent fuel is not practical. And the political climate does not favor a technology that makes potential bomb fuel—plutonium—an item of international commerce. But things might be different in 100 years. For starters, the same fuel could be reprocessed much more easily, since the potentially valuable components will be in a matrix of material that is not so intensely radioactive.

And in 100 years, advances in reprocessing technology might make the economics compelling. The existing American technology dates from the Cold War and involves elaborate

MAP: 5W INFOGRAPHIC; PHOTOGRAPH: COURTESY OF NUCLEAR ENERGY INSTITUTE

The cask and not a mountain: A worker takes radiation readings on casks holding spent fuel at Virginia's Surrey nuclear power plant site.

chemical steps that create vast quantities of liquid waste. But an alternative exists: electrometallurgical reprocessing. Though research into the technique has lagged of late because of the economic climate, the concept might be taken more seriously in the future. Electrodes could sort out the garbage (the atoms formed when uranium is split) from the usable uranium (the uranium-235 still available for fission and the uranium-238 that can be turned into plutonium in a reactor), in something like the way jewelers use electrometallurgy to apply silver plate. Resulting waste volumes would be far smaller.

Perhaps most importantly, in 100 years, energy supply and demand might be very different. Reprocessed nuclear fuel might well become a critical part of the energy supply, if the world has run out of cheap oil and we decide that burning coal is too damaging to our atmosphere. If that happens, we might have 1,000 nuclear reactors. On the other hand, we might have no reactors, depending on the progress of alternate energy sources like solar and wind. At this point, it's hard to tell, but we are not required to make the decision now; we can put the spent fuel in casks for 50 years and then decide if it is wheat or chaff.

There is a final, more practical reason that we might choose to take the plutonium out of spent fuel for reactor use: it makes the remainder easier to store. For the most part, what's left will not be radioactive for nearly as long, and the sheer volume of material will be lower. Mark Deinert, a physicist at Cornell University, says reprocessing, like recycling, removes about half of the material from the waste, dramatically decreasing storage costs and effectively doubling the capacity of a facility like Yucca.

BETTING ON BETTER STORAGE

While nuclear waste would be easier to handle in 50 or 100 years, it would still require isolation for several hundred thousand years. But there is every reason to expect that storage technology will improve in the next century. When we decide to permanently dispose of the waste, either after reprocessing or without reprocessing, we may be smarter at metallurgy, geology, and geochemistry than we are now.

Today, the basic technology at Yucca is a stainless-steel material called alloy 22, covered with an umbrella of titanium—a "drip shield" against water percolating down through the tunnel roof. That could look as primitive in 100 years as the Wright brothers' 1903 Flyer looks to us in 2004. Or it might simply be obsolete. Space-launch technology could become as reliable as jet airplanes are today, giving us a nearly foolproof way to throw waste into solar orbit. The mysteries of geochemistry might be as transparent as the human genetic code is becoming, which would mean we could say with confidence what kind of package would keep the waste encased for the next few hundred thousand years.

Or there might be easier ways to process the waste. For example, particle accelerators, routinely used to make medical isotopes, could provide a means to make the waste more benign. The principle has already been demonstrated experimentally: firing subatomic particles at high-level radioactive waste can change long-lived radioactive materials to short-lived ones. Richard A. Meserve, a former chairman of the U.S. Nuclear Regulatory Commission and now the chairman of a National Academy of Sciences panel on nuclear waste, says this technology, known as transmutation, might become more practical in 100 years. The technology of accelerators has advanced in the last few years, he says, and it is a good bet that it will continue to do so.

Some alternative storage technologies may need only a few more years of research and development. One is ceramic packaging. Ceramics have good resistance to radiation and heat, and they don't rust. At the moment, nobody casts ceramics big enough to hold fuel assemblies, which are typically about four meters long. But there is no theoretical limit to the sizes of ceramics; there has simply been no economic incentive to make giant ones. Nor will there be, until the only likely customer for them, the Energy Department, decides that the metal it is shopping for now isn't up to the job.

Another alternative calls for mixing waste with ceramics or minerals to form a rocklike material comprising about 20 percent waste. The waste would be chemically bound up in stable materials that are not prone to react with water. With a few decades' grace time, engineers could build samples and test them in harsh environments. But even though the idea has been around for more than 10 years, no one has put serious research money into it, since its only possible American customer, the Energy Department, has been committed to Yucca.

That situation shows no sign of change. The Energy Department, following Congress's orders, has so far declined to consider alternatives. Man-Sung Yim, a nuclear researcher at North Carolina State University in Raleigh, argues that some of these technologies are already mature but have been shoved aside in the Energy Department's rush, possibly futile, to open Yucca. "My reading at this point is, people working at the Yucca Mountain project office do not really want to change the design. The more change you bring in, the more delayed the processes," Yim says. "It's a pity, because we could make it better."

CENTRAL CASKING

But the pursuit of the perfect solution (assuming deep geologic disposal even could be perfected) has ignored a realistic solution. And when the perfect fails, as now seems likely, we will be left with something no rational person would have chosen: waste sites scattered from coast to coast, in places where reactors used to be, each

Old dome day: In September, contractors demolished the containment dome of the decommissioned Maine Yankee nuclear power plant in Wiscasset, ME. The rubble was removed, but the old reactor fuel rods stayed behind as nuclear orphans in casks at the derelict site.

AP PHOTO/ROBERT F. BUKATY

with its own security force, maintenance crew, and exclusion zone. "We're here to run a business as efficiently as possible," says John Sanchez, the project manager who oversaw the planning for the pad at Indian Point when he worked at Consolidated Edison, the site's former owner. "In a perfect world, you would not have 60 of anything, if you could have one." But after 20 years of pursuing geologic disposal, and 15 years of chasing Yucca and avoiding any mention of a plan B, just such an ad hoc, and suboptimal, solution is emerging.

And it's emerging without the support of the Energy Department. Testifying before the Senate Energy Committee over the summer, Kyle McSlarrow, the Energy Department's deputy secretary, said that "continued progress toward establishing a high-level waste repository at the Yucca Mountain site is absolutely essential." He told another committee on the same day that with progress toward Yucca's opening, "industry saw clearly that the nuclear-power option was truly back on the table." (The department would not make McSlarrow or other officials available for comment for this article.)

Cask storage is not pretty, but what's wrong with the idea of an industrial repository, a few hectares set aside for the next century or so, a single, guarded location in a little-populated area, a location that in ten years or so will be remarkable only because it's a place where the snow doesn't stick? Macfarlane of MIT says making such a site secure and terrorist-proof would cost $6.5 billion, at most. "Isn't that worth it? How much have we spent on Iraq? Look what we got for that money. And there's more at risk here," she says.

Finding a central site poses obvious challenges; nobody wants any type of radioactive waste site in his or her backyard. But after extended negotiations, a group of utility engineers, including Sanchez, cut a deal with the Skull Valley band of the Goshute Indian tribe for a long lease on part of its reservation 80 kilometers west of Salt Lake City. The area already hosts an air-force bombing range, a nerve-gas depot and incinerator, and a dump for low-level radioactive waste; the Goshutes figure they can use the rent to buy themselves land in a nicer neighborhood.

Some experts think the federal government could take over the Goshute project and push it to completion, but there is a snag—an ironic one, given the fears of a September 11–style attack on a nuclear site. The Nuclear Regulatory Commission has determined that an F-16's crashing into the casks on its way to or from the test site is a "credible accident." But while such a crash would doubtless be disastrous, casks do provide some safety advantages over today's fuel pools. The fuel in casks is much more spread out and does not require a flow of cooling water to prevent spontaneous, spreading fire. Thus the worst-case effects are more limited. In any case, one remote central site would be easier to protect with air defenses than numerous scattered sites.

Those scattered sites are already creating local problems. The casks from the former reactor in Wiscasset, ME, are blocking the redevelopment of the peninsula where they're stored, a valuable industrial site. A cask site near the Prairie Island Nuclear Generating Plant in Welch, MN, is adjacent to a tribal day-care center and casino, which is nobody's idea of a long-term solution. Inevitably, in the wake of September 11, the Indian Point casks will be a locus of fear. These outcomes will seem even sillier in 30 years, when many of the reactors that made the waste are gone.

Sanchez recalls carrying a picnic lunch to the stand of maples and black-walnut trees now being replaced with a concrete pad for storing nuclear waste. As the years roll by, fewer and fewer people will know those trees existed. Several decades from now, as today's aging nuclear power plants are decommissioned, people may not remember that the reactors themselves existed. If we don't take action soon, however, casks of waste will stand alone on that bluff above the Hudson River—and in dozens of other places across the country. TR

Matthew L. Wald, a reporter in the Washington bureau of the *New York Times*, has written about the nuclear industry for 25 years.

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TO FIGHT, VERIZON SWITCHES

The biggest U.S. phone company is scrapping a century's worth of network technology to embrace Internet-style packet switching. Will it be enough to keep Verizon relevant in a media-soaked world?

BY MICHAEL FITZGERALD

VERIZON'S FUTURE STARTS where the scuffed green floor ends on the second story of a windowless brick blockhouse in Baldwin Park, CA, a Latino community east of Los Angeles. Past that point, the building's old asbestos-filled floor tiles were removed in March and replaced with shiny white ones, marking the place where circuit switching, the method long used to connect one phone to any other, gives way to packet switching, the technology that makes the Internet so powerful. It's a project that promises to change Verizon's business—and eventually, the way we all think about phone service.

Pamela and Grant Jacoby, husband-and-wife members of the Verizon project team who are showing off their new system to a reporter, say they celebrated their anniversary by going to dinner and then coming here to watch a HazMat team rip out the old flooring. Romantic? No. "But how many times do you get to see that?" says Grant, as his wife laughs.

The reason for the Jacobys' excitement is simple: in Grant's words, "We're getting rid of the public switched telephone network." But what does Verizon, the nation's biggest phone company, build in its place? A new network that makes more efficient use of its switching stations and physical wires by working more like the Internet, and that wires up customers' homes with high-capacity fiber-optic lines. With such an infrastructure in place, the theory holds, the longtime supplier of plain old telephone service can change into a new kind of company, one that can compete in a world where media giants like Comcast are blending services such as television, telephone, and Internet access.

DAVE LAURIDSEN

Long-distance relationship: At the just-overhauled Verizon central office in Baldwin Park, CA, husband-and-wife engineers Grant and Pamela Jacoby say they're proud to help lead the company's changeover to packet switching.

Listen to people like the Jacobys, and it's easy to imagine that in a few years Verizon customers may not even have phones, or at least not ones that only make phone calls. Instead, they'll have devices that surf the Web, transmit video phone calls and still pictures, and deliver TV programming, TiVo style. Customers will use their cell phones to instant-message their kids' TV screens that it's time to stop playing video games and start doing homework. They'll control what their phones—or rather, their personal telecommunications networks—do in a way that's simply impossible today.

Or at least, that's what Verizon executives hope. The company astonished Wall Street and telecom insiders in January when it announced that it would spend $2 billion over the next two years to move to Internet-type switching—a far more ambitious overhaul than those planned by its sibling phone companies, such as SBC and BellSouth. (Verizon's changeover is distinct from the other hot trend in telephony, voice-over-Internet-Protocol services; those run primarily on the Internet, not the phone network.) But while projects like the Baldwin Park conversion are well under way, Verizon managers admit they're spending the money without a full understanding of how the new network will be used or what services consumers will want most. According to Paul Lacouture, president of Verizon's network services group, it's an investment the company has to make simply to survive in a fast-changing industry. Moving to packet switching now, he says, means "we future-proof our network."

THE PARANOID UNDERTAKER

It would be easy to mistake the Baldwin Park central office for a museum of the history of telephony: the building has hosted three generations of phone network technology since its construction early in the last century. The first and longest-lived technology was the step switch. Legend says that its inventor, a Kansas City mortician named Almon B. Strowger, was convinced that switchboard operators were sending his customers to rivals. So he built an electromechanical device that automatically routed calls according to the numbers dialed by customers and patented it in 1891. For decades, step switches occupied thousands of central offices, whirring, clicking, and banging as they opened circuits and shunted calls to their destinations.

In Baldwin Park, the mechanical step switches were finally ripped out in the 1970s and replaced with digital switches. All that's left of the old apparatus are two walls of steel coils big enough to hold wine bottles. Now 11 rows of digital circuit-switching equipment house thousands of playing-card-sized circuit boards. Copper wires running from homes and businesses across Baldwin Park and parts of adjacent communities terminate here; to the phone network, these circuit boards are you, me, and our neighbors and employers.

In circuit-switched networks like Baldwin Park's, a given phone call has exclusive access to a circuit, or phone line, for its entire duration. "The minute you dial your number…you've tied up a certain amount of bandwidth," says Stuart Elby, Verizon's vice president of network architecture and enterprise technologies. "So you waste a lot of space." But the share of phone network capacity devoted to voice calls is declining fast, while data traffic is increasing, and today's third wave of change—the transition to packet switching—is a response to that shift.

Packets are dollops of information labeled with addresses so that a computer network can forward them, node by node, to their intended recipients. As long as each packet is reunited with its neighbors at its destination, it doesn't matter how it gets there—which means that billions of packets with different destinations can travel through the same physical wires at the same time. Though it's the very foundation of the Internet, packet switching is a relatively old technology, first developed in the 1960s. But turning voices into packets is relatively new, and until recently the audio quality of packet-switched calls lagged far behind that of circuit-switched calls. As recently as three years ago, most engineers at traditional phone companies still sneered at packet switching. "Saying that Internet Protocol was going to be the most important protocol—well, that could be a career-limiting move," laughs Elby.

Out with the old: On "cut night," the red "hot patch" cables keeping old digital switches in business at Verizon's Baldwin Park office (top) will be removed, and new packet-switching equipment (bottom) will take over.

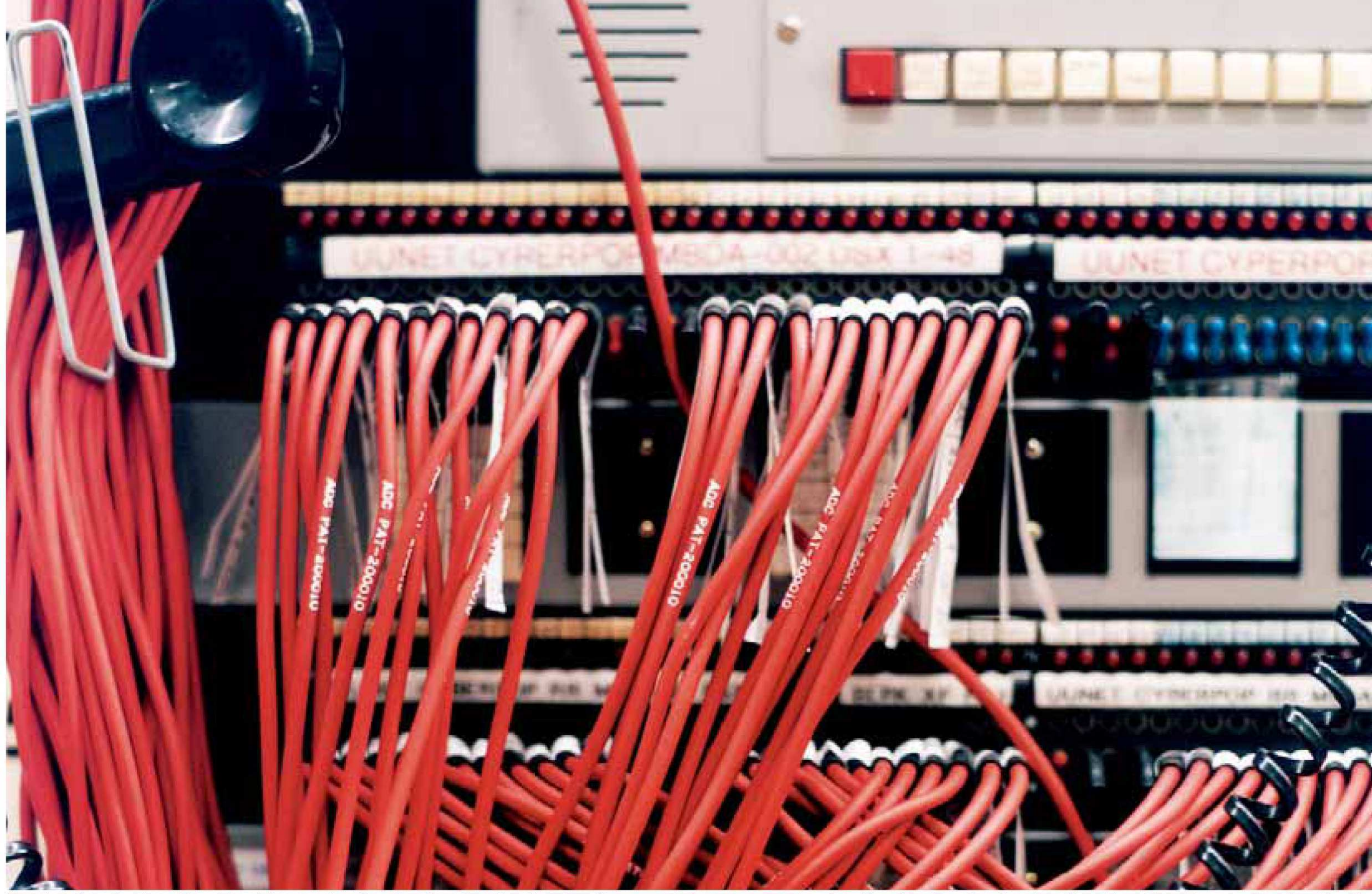
No one's sneering now. Verizon's biggest fear is missing the opportunity presented by packet switching, which cable companies like Comcast are quickly seizing upon to offer voice and data services in addition to their traditional TV packages. Packet-switched networks are not only more capacious; they're also cheaper to run. A single 100-centimeter-by-60-centimeter "softswitch"—so called because it uses software commands to handle both Internet-type packets and the older data formats used for many voice calls—accommodates as many phone lines as a 10-meter row of digital circuit switches. That saves on maintenance, and even better, it means Verizon can combine central offices: another California office, for instance, will be managed remotely by software running at Baldwin Park.

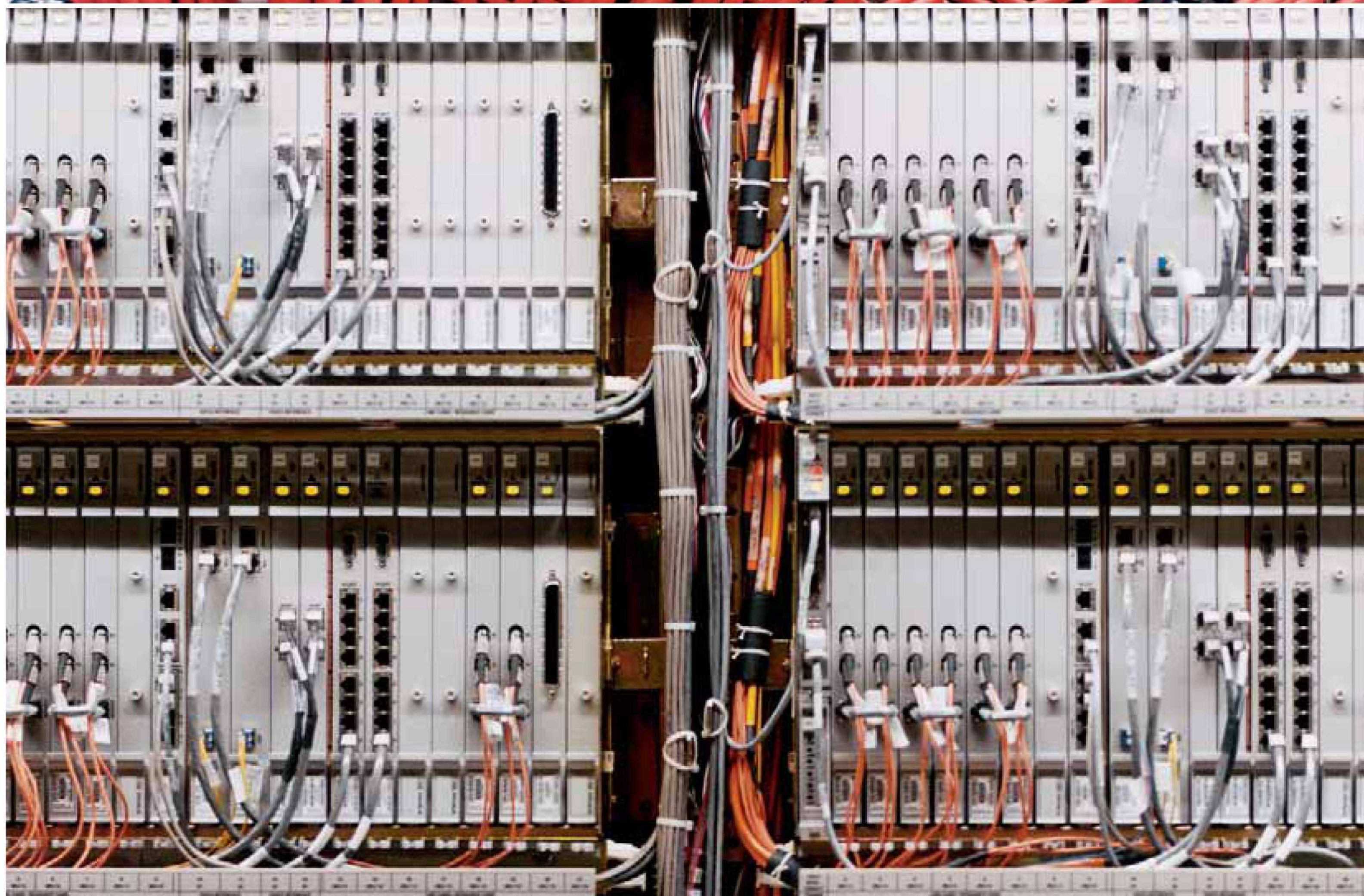
Verizon set a highly ambitious schedule for the first rollout of its new packet-switching equipment. The southern-California team assembled at the Baldwin Park office one day in early August gripes good-naturedly about the pace. Lead engineer Bill McClure says that during a conference call in February, he and fellow lead engineer Curtis E. Reese learned that they'd have until July 2 to refit five sites that handled a total of 100,000 telephone lines—a shock to engineers accustomed to testing small things for 18 months apiece. "When they said that, Curt passed out," jokes McClure, a 32-year veteran of the company. "And then I passed out."

"And then they told me, and I passed out," chimes in Pamela Jacoby, the project leader. They recovered fast: this is, after all, the kind of assignment that caps a network engineer's career. But that doesn't make it easy. There have been plenty of double shifts and unexpected bugs. Baldwin Park is one of the first and biggest central offices to convert to packet switching, and impromptu conference calls between Verizon engineers and their counterparts at telecom equipment supplier Nortel can happen several times a day.

Getting the new equipment to work with older ISDN technology was one stubborn problem. It also showed what it will take to integrate packet-switching with the old phone network, which Verizon can't simply turn off. Many retail and banking customers still send credit card and other transactions over ISDN connections, a 1990s predecessor to DSL. But the information traveling on one of the ISDN data channels wouldn't transfer over to the packet switches. "That took three or four weeks to figure out," Reese says.

DAVE LAURIDSEN





Engineer's engineer: Verizon executive Paul Lacouture oversees the network overhaul. "He's turned a few nuts and bolts in his time," says Pamela Jacoby.

The team missed the July 2 deadline, largely because of state regulations requiring phone companies to give 30 days' notice of equipment changes. But the delay gave the team extra time to resolve technical problems like the ISDN bug. Verizon's first fully packet-switched central office went live in mid-September; at press time, however, the changeover at Baldwin Park was temporarily on hold while Verizon attempted to resolve related legal issues.

Those first five stations handle only a small fraction of Verizon's customers in the region, but the pace of the rollout is expected to increase, and the company's entire network could be converted in as little as five years. It'll be a while before customers actually see a difference in services; Verizon won't become an amalgamated phone-cable-broadband company with gee-whiz packet-switched services until it actually has a good base of switches in place. But already, thanks to a parallel effort at Verizon to string fiber-optic cables from the curbside all the way into people's living rooms, Verizon customers in places like Keller, TX, Tampa, FL, and Huntington Beach, CA, have spiffy new "optical network terminals" pumping up to four phone lines, television service, and 30 megabits per second of data into their homes (DSL tops out at about three megabits per second).

ON THE OFFENSIVE

Baldwin Park is 4,500 kilometers and three time zones away from Verizon headquarters in New York. But creating a packet-switched network that traverses that distance is the goal of Paul Lacouture (pronounced LACK-uh-chur), the executive responsible for executing Verizon's grand plan. Lacouture inhabits a 39th-floor office that once featured a view of the World Trade Center, and his desk is the size of a conference table. But engineers who work for Lacouture say they sense a kindred soul. "It seems like he's turned a few nuts and bolts in his time. You don't often see that in upper management," says Pamela Jacoby.

Indeed, Lacouture started out as a network engineer 31 years ago, at the old New England Telephone (which became part of Nynex, which became part of Bell Atlantic, which merged with GTE in 2000 to become Verizon). And the ex-engineer shares the California team's excitement about the shift to a packet network. "It's something that you want to do" as an engineer, he says.

> "The information age is really just beginning. We'll be in a position to package wireless, voice, data, and video. It's a tough transition, but we think we can grow there." —**PAUL LACOUTURE, PRESIDENT, VERIZON NETWORK SERVICES GROUP**

But it also makes business sense. Like all traditional phone companies, Verizon faces enormous competitive pressure. Cellular phones, cable telephony, and voice-over-Internet services like Vonage and Skype are steadily chipping away at its base of residential customers *(see "Skype beyond the Hype,"* TR *June 2004)*. Even more alarming, from Verizon's perspective, is a gradual drop-off in minutes used per line. Yet at the same time, Verizon's broadband and data businesses are booming. When, in late 2003, the cost of installing packet-switching equipment finally dropped to levels comparable to those of traditional circuit-switching equipment, Lacouture realized that it was time to embrace a new future. "The information age is really just beginning," he says. "We'll be in a position to package wireless, voice, data, and video. It's a tough transition, but we think we can grow there." After years of simply trying to preserve the company's market share against competitive forces, Lacouture says, "this was a chance for us to be on the offensive."

Still, it is a difficult strategy. Customers won't be able to take advantage of packet switching for services like full-motion video unless they have true broadband connections, and Verizon believes that means running fiber-optic cable to each home or business that wants it—a costly proposition. The central-office upgrades must continue, of course, and though much of Verizon's backbone network already uses packet switches, it's upgrading those, as well: the company is the first buyer of Lucent Technologies' Lambda Xtreme switches, high-end optical switches each capable of handling 1.3 to 2.6 terabits of data per second. This enhancement, while not as costly as fiber to the customer, is also not cheap.

In fact, Verizon's upgrades will cost enough that its siblings have opted for more limited plans. BellSouth, for example, believes that technologies like DSL and Ethernet can deliver data to homes at speeds sufficient for television; it's laying fiber-optic cables to the curbside in many neighborhoods and switching to copper wires for the last 100 meters or so. SBC is doing the same in its existing service areas, reserving "fiber to the premises" for new housing projects. Lacouture, however, remains convinced that copper is a dead end. He believes these companies will eventually wind up doing the same infrastructure work Verizon is—and by then, he says, Verizon will have a huge head start.

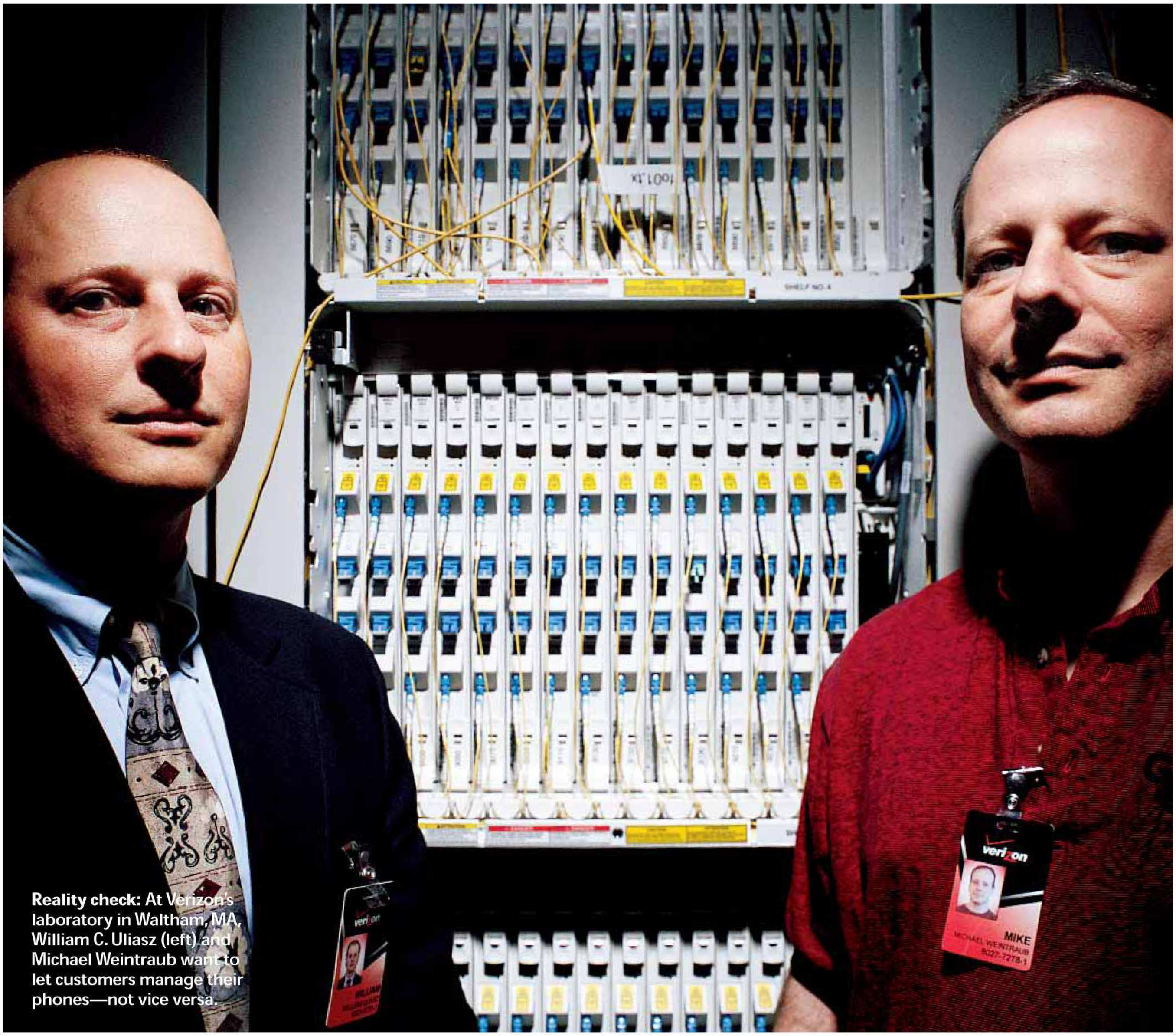
But bets on media "convergence" have seriously damaged other companies, including Vivendi Universal and (ominously) AT&T. In the late 1990s and 2000, under then CEO Michael Armstrong, AT&T spent more than $100 billion buying McCaw Cellular and cable providers TCI and MediaOne in order to offer local-phone and TV service and position itself for a broadband future. AT&T overspent, and both the technology and consumer demand moved more slowly than expected, which left the company vulnerable when recession hit. AT&T sold off its broadband business, has steadily lost market share, and recently abandoned its pursuit of the consumer long-distance market.

AT&T actually had the right idea, argues veteran telecommunications consultant Frank Dzubeck, but realizing it would have required technologies that didn't yet exist. "The implosion of the industry killed [Armstrong's] vision," he says. Verizon is a different animal: it's a $67 billion behemoth with an established grip on local service, the third-biggest U.S. long-distance company, and in partnership with Vodafone, the biggest U.S. cellular company. Put it all together, Dzubeck says, and Verizon has everything it needs to kill itself—and then raise itself from the dead.

CUSTOMERS IN CONTROL

At least Lacouture doesn't have to worry about whether the technology will work. Engineers at Verizon's laboratories, especially its huge research quadrangle in Waltham, MA, have spent

DENNIS KLEIMAN



Reality check: At Verizon's laboratory in Waltham, MA, William C. Uliasz (left) and Michael Weintraub want to let customers manage their phones—not vice versa.

CHRISTOPHER HARTING

more than a decade looking at packet switching and know it can deliver. "We're a reality check and a stability check," says William C. Uliasz, director of Verizon's optical transport network architecture group in Waltham.

The Waltham lab is where engineers developed a 12,000-page set of requirements for packet switches, to help manufacturers like Nortel develop products. It's here that researchers attempt to bog down the fastest long-distance network on the planet—3,000 kilometers of fiber rolled up into a couple dozen spools. And it's here that software developers created the Universal Media Communicator, a program for desktop PCs that lets users seamlessly transfer calls from cell phones to wireless PDAs to traditional landlines to IP phones, without ever putting anyone on hold. One of the program's myriad features represents separate phone calls as icons that users can drag and drop to initiate conference calls. The idea is to let the customers control their phone service—where calls reach them, say, or when and whether their phones ring.

It's unclear how much of the Universal Media Communicator will show up in actual Verizon products; for now, the company is using it to inspire programmers at conventional software companies, including Microsoft, to develop applications for the Verizon network, says Michael Weintraub, director of converged services at the lab. "A lot of people think you want to blow up the public switched telephone network. But what you really want is this evolution" to Internet Protocol, Weintraub says. It isn't that the current network is so bad—it's just that packet-switched networks make everything faster, cheaper, and easier to use. And they turn the tables on who has control.

But will people pay for the new features enabled by packet switching? Come to think of it, what *will* people pay for, once voice calling is simply one entrée on a vast menu of potential services?

That's still the big unknown. The phone companies are famously wrong about when customers will want things. AT&T first demonstrated the videophone in the 1960s. Ten years ago, phone companies thought ISDN was the path to broadband. Then DSL was supposed to be the high-speed enabler for video on demand but became mainly a way to browse the Web faster.

"We always guess wrong," shrugs Verizon's Elby. "So we know that we won't come up with the killer app—but we'll have the network to support it." TR

Michael Fitzgerald is a freelance writer based in Massachusetts.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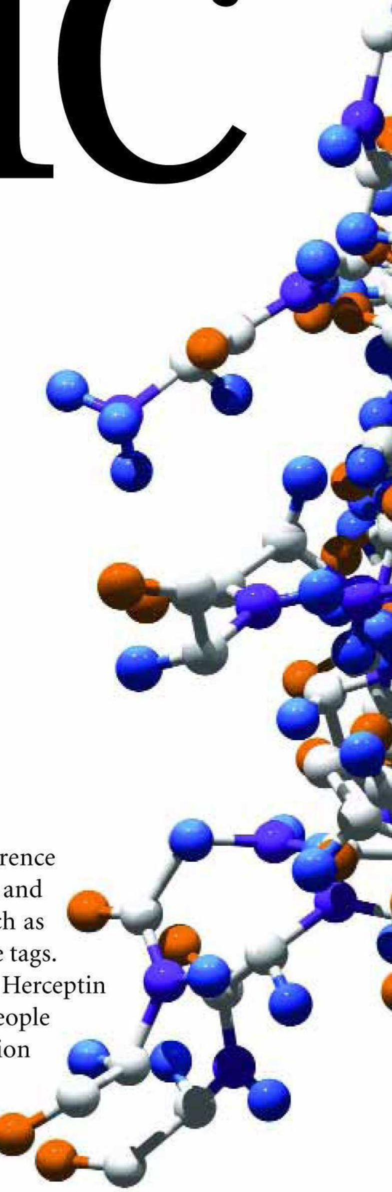
generic biotech

High-tech copies of natural proteins established the biotech industry and continue to save lives. But the cost of biotech drugs can be astounding, and though patents on the first of them are expiring, generic versions are nowhere in sight. Can the United States find the political will and technical know-how to develop biogenerics?

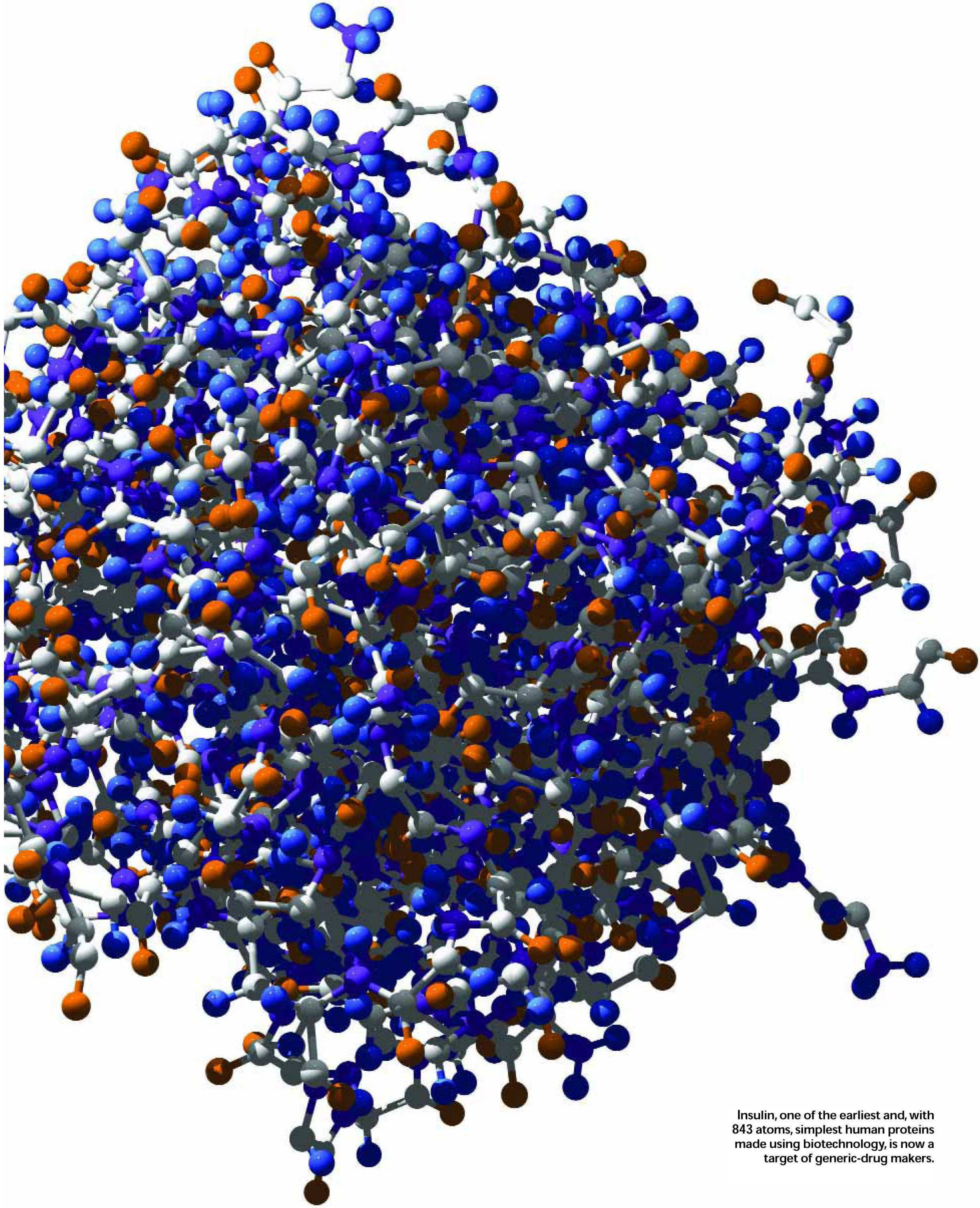
BY ERIKA JONIETZ • ILLUSTRATIONS BY JOHN MACNEILL



Since their inception in the 1980s, biotech drugs based on natural proteins have come to mean the difference between life and death for millions of patients, treating diabetes, cancer, multiple sclerosis, heart attacks, and numerous genetic diseases. They boost the quality of life of millions more, people with conditions such as rheumatoid arthritis and Parkinson's disease. But such "large molecule" drugs also come with large price tags. Interferon beta, used to treat multiple sclerosis, runs $10,000 to $14,000 a year. Cancer treatments such as Herceptin can cost $20,000 to $30,000. And the prices of drugs for some rare diseases can top $200,000 annually. "People need these drugs for their survival," says Abbey Meyers, founder and president of the National Organization for Rare Disorders. "If they can't afford it, they're dead."

Patents on the first biotech drugs began expiring three years ago *(see "Some Would-Be Biogenerics," p. 58)*, but the less-expensive generic versions that typically appear as soon as a drug loses patent protection have yet to hit the U.S. market. If you believe the arguments of pioneering biotech companies like Genentech and Amgen, the problem is the complexity of protein-based drugs—or "biologics"—which makes their duplication extraordinarily difficult. Without exact duplication, generics producers risk introducing drugs that may not work or could even harm patients. "Anything can be reverse-engineered and copied," Robert Garnick, Genentech's senior vice president for regulatory affairs, quality, and compliance, told a U.S. Food and Drug Administration panel in September. "However, some things are much safer [to copy] than others."

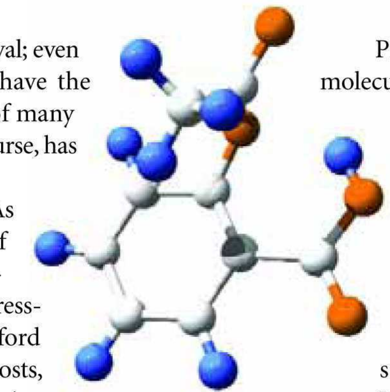
But the fact is that several companies already sell generic versions of protein drugs in, for example, China and Latin America. The European Union is likely next. Such "biogenerics" don't exist in the United States mainly because there is no mechanism for their approval and sale. The FDA has repeatedly delayed promised guidance on what sort of testing bio-



Insulin, one of the earliest and, with 843 atoms, simplest human proteins made using biotechnology, is now a target of generic-drug makers.

generics will need to undergo to obtain approval; even if it does deliver guidelines, it might not have the legal authority to approve generic versions of many biotech drugs. And the biotech industry, of course, has already begun lobbying against biogenerics.

But their time may nonetheless be ripe. As costs for biologic drugs rise, and the number of expired patents grows, patient groups, health-care payers, and generics manufacturers are pressing for change. Few patients can actually afford biologics, and even when insurers cover their costs, the drugs constitute an insupportable and growing burden on the health-care system. Medicare, for instance, spends an estimated $1 billion per year for erythropoietin, a protein used to treat anemia in cancer and kidney failure patients. Kaiser Permanente, the largest HMO in the United States, saw its expenditure on biologics more than triple between 1998 and 2003 and expects that figure to double again by the end of 2005.



Much simpler than the tiniest protein, aspirin *(above)* and other "small molecule" drugs can be duplicated cheaply and easily.

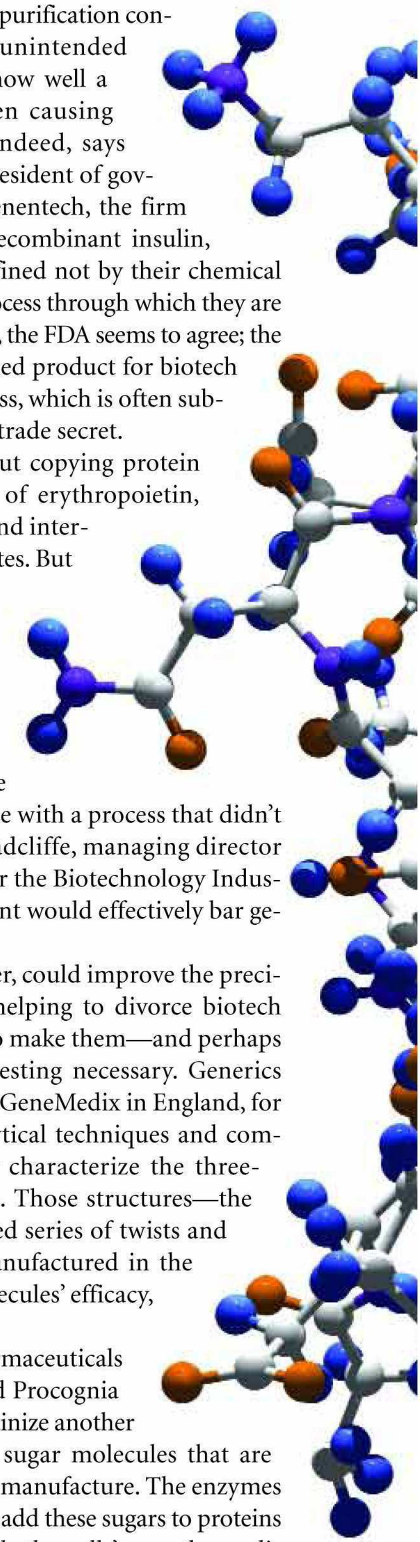
This situation, in which some patients' only hope is a ruinously expensive patented drug, was also characteristic of traditional "small molecule" drugs until the advent of conventional generics—and it helped earn the pharmaceutical industry a reputation for greed. "The biotech industry, by and large, has been spared the negative public image that the pharmaceutical companies have acquired," says MIT economist Ernst Berndt. "The whole issue of generic entry is putting them in a very uncomfortable position that makes them look like big pharma."

A growing number of traditional generics makers and upstart biotech companies hope to paint exactly that picture of biotech pioneers. New technologies, they say, allow them to prove that their much cheaper copies of drugs are identical to the originals—and just as safe and effective. Legislators and regulators are taking notice. In June, the U.S. Senate Judiciary Committee held hearings on the issue, and the FDA began a series of workshops in September designed to assess the risks inherent in biogenerics and the technologies available to mitigate them. Though the issues are complicated, more and more experts believe that U.S. patients will eventually have access to biogenerics.

THE PROTEIN PROBLEM

Would-be biogenerics makers face two major obstacles in the U.S. market. The larger of the two is the lack of a regulatory framework governing generic protein drugs. But this problem is bound up with the other: how to prove that a generic biologic is chemically and therapeutically equivalent to the original. For conventional pharmaceuticals such as aspirin, or even state-of-the-art drugs like Lipitor or Viagra, the process is straightforward. These drugs comprise relatively simple, small molecules that generics makers can synthesize directly in the lab and then analyze chemically to ensure that they are pure and identical to the name-brand versions. The FDA approves generics based on this proof, plus small clinical trials that typically include about 30 patients, to show that the body metabolizes the copies in the same way that it does the originals. Since generics companies don't have to conduct large and expensive clinical trials (or pay for the original R&D), they can sell the drugs cheaply and still turn a profit.

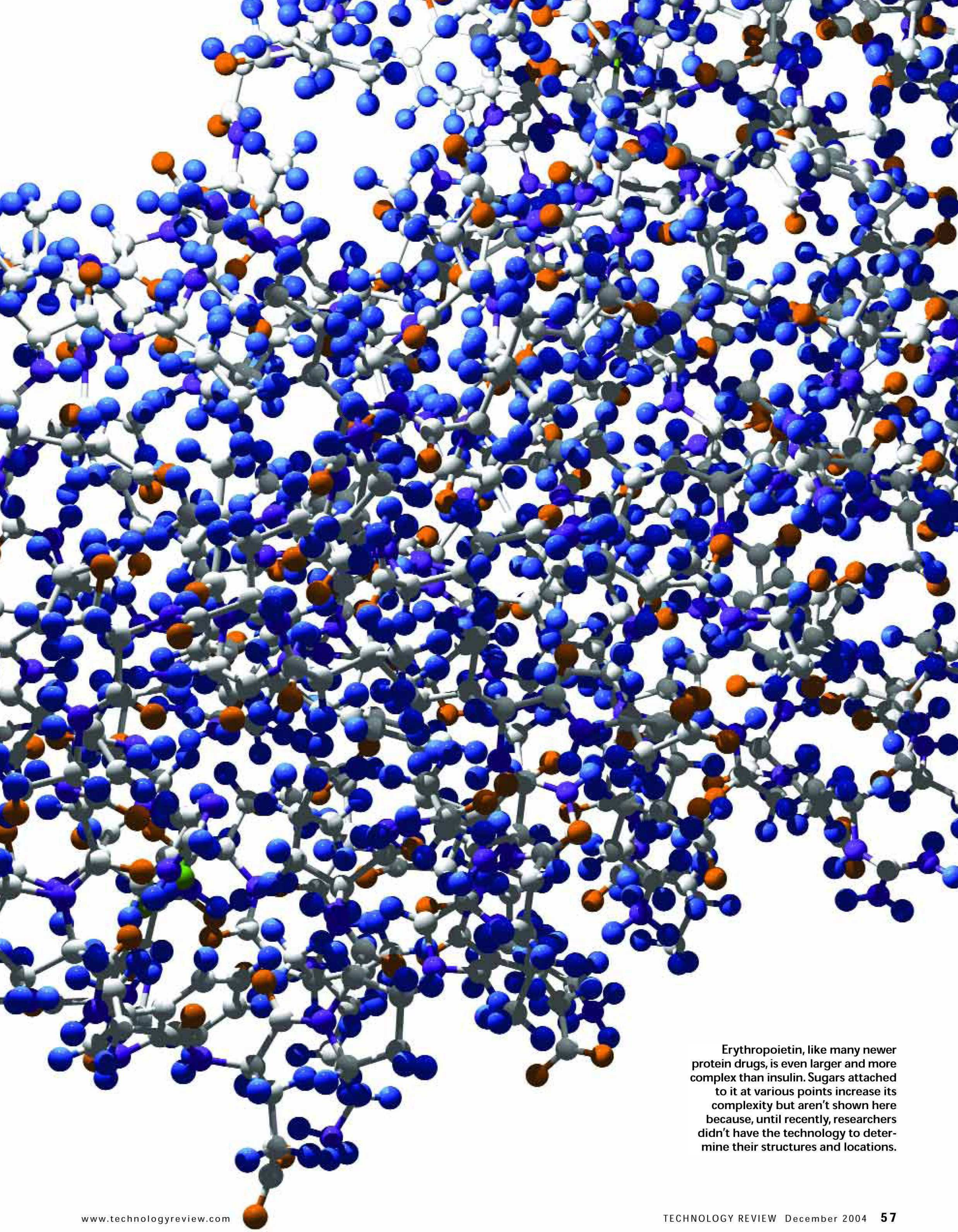
Protein drugs, in contrast, are huge, complicated molecules. Chemists can't manufacture them cheaply, or in some cases at all, so biotech companies instead genetically engineer bacteria and other cells to do so. The reliance on living cells gives the process a black-box quality; small changes in, say, temperature or purification conditions can have unintended results, affecting how well a drug works or even causing severe side effects. Indeed, says Walter Moore, vice president of government affairs at Genentech, the firm that first produced recombinant insulin, "our products are defined not by their chemical makeup but by the process through which they are made." To some extent, the FDA seems to agree; the agency approves not only the finished product for biotech drugs but also the production process, which is often subject to separate patents or held as a trade secret.



None of this, however, rules out copying protein drugs. Multiple patented versions of erythropoietin, insulin, human growth hormone, and interferon beta are sold in the United States. But each version varies slightly from the others and has gone through the full gamut of clinical testing required of a new drug—a qualification that some biotech innovators insist every protein drug, unique or copy, should have to meet. "This trade association would be uncomfortable with a process that didn't include clinical trials," says Sara Radcliffe, managing director for science and regulatory affairs for the Biotechnology Industry Organization. Such a requirement would effectively bar generic competition.

Emerging technologies, however, could improve the precision of protein characterization, helping to divorce biotech products from the processes used to make them—and perhaps reducing the amount of clinical testing necessary. Generics companies such as Israel's Teva and GeneMedix in England, for instance, use ever improving analytical techniques and computational methods to accurately characterize the three-dimensional structures of proteins. Those structures—the products of exceedingly complicated series of twists and folds as the proteins are being manufactured in the cell—profoundly influence the molecules' efficacy, potency, and side effects.

Startups such as Momenta Pharmaceuticals in the United States and U.K.-based Procognia have developed technologies to scrutinize another source of proteins' fickleness: the sugar molecules that are often attached to them during their manufacture. The enzymes in mammalian and human cells that add these sugars to proteins follow rules that seem to vary with the cells' growth conditions, so figuring out the number and types of sugars attached to a particular protein has proved especially challenging. Momenta has combined proprietary enzymes, traditional analytical techniques, and unique computational algorithms to



Erythropoietin, like many newer protein drugs, is even larger and more complex than insulin. Sugars attached to it at various points increase its complexity but aren't shown here because, until recently, researchers didn't have the technology to determine their structures and locations.

precisely map such sugars. Procognia uses sugar-detecting arrays, analogous to gene chips that analyze gene sequences or activity, to do the same thing. "From a technical standpoint, I believe it's possible to completely characterize a protein," says Alan Crane, Momenta's CEO. "If you can show it's all the same, what are the arguments for not allowing a generic?"

BIOGENERIC BUREAUCRACY

Technical arguments aside, many contend that the FDA doesn't even have the authority to approve most biogenerics. When U.S. generic-drug laws were passed in the 1980s, the brand new, complex biotech drugs were not under discussion. "At the time they were debating, it didn't occur to anyone that technology would advance to the point it would be possible to create generic biologics," says Janice Reichert, a senior research fellow at the Tufts Center for the Study of Drug Development. As a result, existing generics legislation applies only to small-molecule drugs, not biologics.

During a 2003 push to improve patient access to drugs, the FDA announced plans to issue guidelines that would begin to define an approval process for generic protein drugs, but they have so far been delayed twice—perhaps because of the agency's uncertainty over its legal position. Even those guidelines, regulators have indicated, would apply only to a few biologics: relatively simple, well-defined proteins such as human growth hormone and insulin. (In fact, Sandoz, the generics arm of Swiss drug company Novartis, has already submitted an application for a generic version of human growth hormone in the belief that the FDA has the authority to approve it.) The easiest solution would be an extension of existing generics laws to cover all protein-based drugs, and Senators Orrin Hatch and Patrick Leahy seem primed to take that action. The pair sponsored hearings on biogenerics within the Senate Judiciary Committee in June, and Leahy's staffers say he hopes to introduce legislation in 2005 that would apply the framework for small-molecule generics to biologics.

Biotech companies will inevitably fight such legislation, just as traditional drugmakers opposed the advent of small-molecule generics. Many of the current arguments parallel those made two decades ago. Companies assert, for instance, that copycat proteins will cut into revenues so severely that the expensive research needed to develop new lifesaving drugs will slow or even halt. The pace of innovation in small-molecule drugs, however, suffered no such deceleration. Indeed, generics have forced pharmaceutical companies to develop improvements, such as time-release or longer-acting formulations, in an effort to maintain market share.

In the meantime, the FDA has begun a series of public workshops designed to assess the available technology and get feedback from stakeholders. The first session, held in September and designed to help regulators assess scientific arguments, became a highly polarized back-and-forth between biotech pioneers and biogenerics makers. The agency has so far remained silent about the form any rules might take and has planned a second workshop for early 2005.

But even when biogenerics do appear in the United States, patients and insurers might not see the same cost savings they have with traditional generics. "The prices may not go down as much," says Momenta's Crane, "because the hurdles are higher in the first place." The lower prices of generic drugs—typically 50 to 66 percent those of the originals—stem from their abbreviated approval process and from the fact that many states mandate generic substitution at pharmacies, so manufacturers can dispense with costly marketing. Biogenerics will almost certainly face stricter preapproval testing requirements than small-molecule generics, at least until the FDA gains confidence that copycat proteins can be analyzed well enough to prove that they are identical to the originals. And most biologics are administered in hospitals rather than dispensed at pharmacies; since generics companies may face an uphill battle convincing doctors of the safety and efficacy of their drugs, this means more spending on marketing.

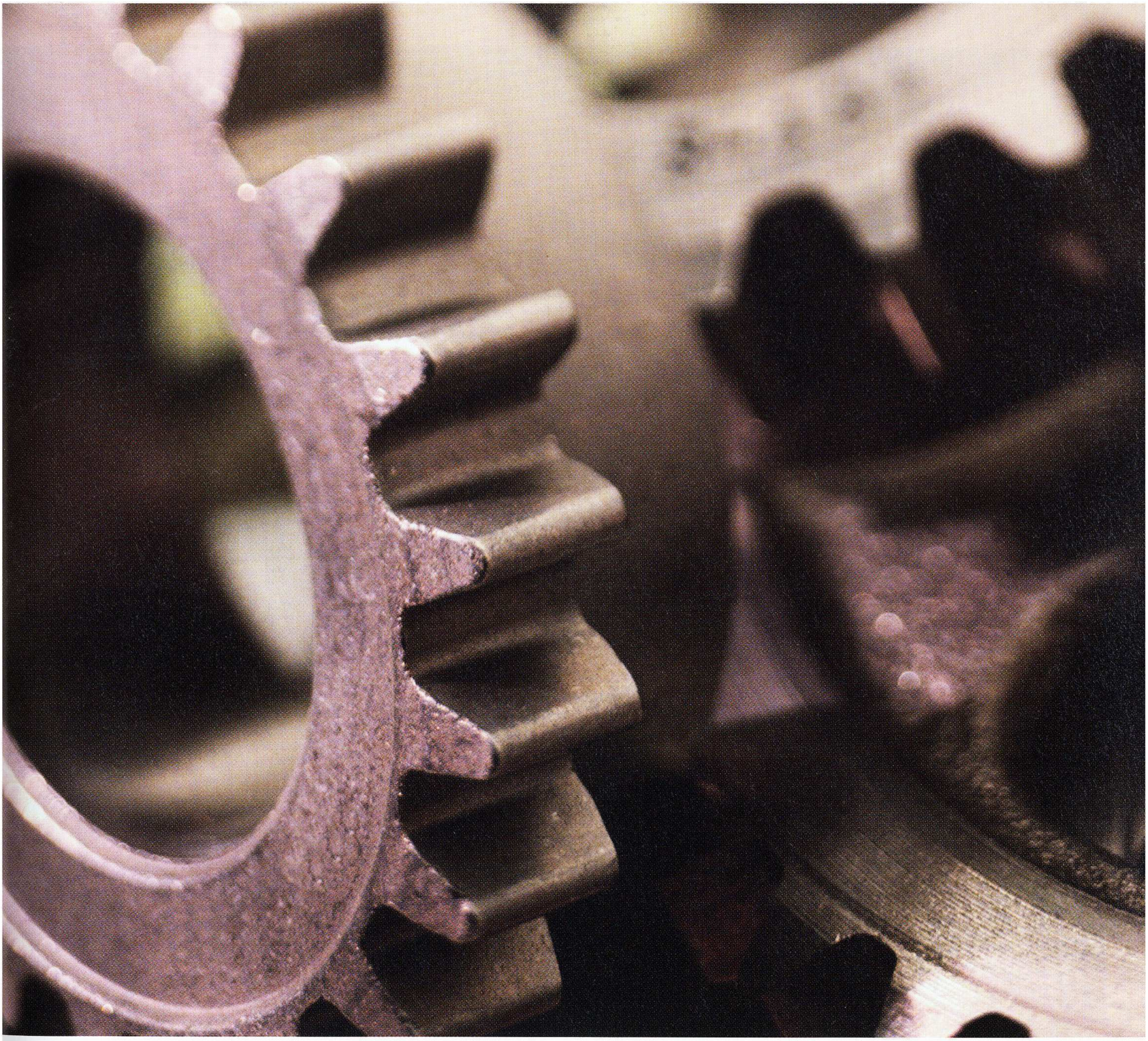
Still, says Carole Ben-Maimon, president of biogenerics developer Duramed Research, a back-of-the-envelope calculation shows that in the long run, biogenerics—particularly self-administered drugs such as insulin and human growth hormone—may reach the half-off mark. John Langstaff, CEO of Canadian biogenerics company Cangene, similarly believes that a 40 percent price drop is possible for some drugs. Others see decreases of 10 percent to 20 percent as more realistic. Though not ideal, even a 10 percent discount would be significant for drugs costing thousands of dollars each year.

Biogenerics are almost certain to make their U.S. debut within the next five years: costs will compel it, technology will enable it, and politics will delay it. In the most optimistic vision of the biogeneric future, diabetics will be able to control their condition for the cost of a daily latte, and cancer sufferers will be able to fight their disease without bankrupting their families. Lower costs could also make insurers, including federal and state agencies, more willing to cover biologics, further expanding their availability. As the number of invaluable protein drugs swells, biogenerics will become not just helpful but essential—driving a new sort of biotech revolution. TR

Erika Jonietz is a *Technology Review* contributing editor based in Texas.

SOME WOULD-BE BIOGENERICS

DRUG	CONDITION TREATED	U.S. PATENT EXPIRATION
Insulin	Diabetes	2001
Human growth hormone	Short stature and muscle wasting associated with AIDS	2003
Interferon beta-1a	Multiple sclerosis	2003
Erythropoietin	Anemia associated with kidney dialysis or cancer treatment	2004
Alteplase	Heart attack, stroke, blood clots in the lungs, and other conditions involving blood clots	2005
Filgrastim	Low white-blood-cell count and risk of infection associated with cancer treatment	2006



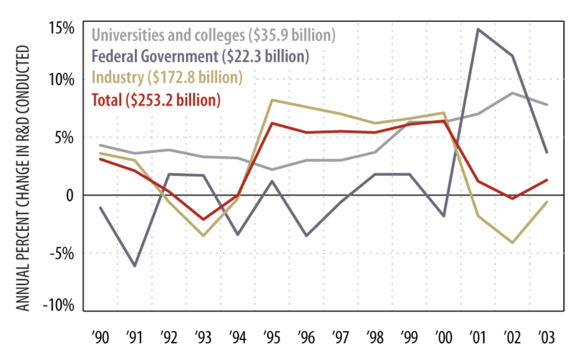
R+D 2004

WHO'S SPENDING WHAT ON RESEARCH AND DEVELOPMENT? *TECHNOLOGY REVIEW* RANKS THE TOP 150 COMPANIES.

Corporate spending on research and development remains the driving force behind innovation. Indeed, the five corporations with the largest R&D budgets alone spent $33.6 billion last year, more than the U.S. government spent on R&D conducted by federal agencies. But a troubling trend that began in 2001 continues: corporate R&D spending is on the decline. Last year's decrease of .6 percent is slight, but it follows sharper declines in 2001 and 2002, after more than a half-decade of robust growth. Perhaps most worrisome, the declines were not limited to a few obviously troubled sectors, such as telecommunications, but affected a cross section of industries and included some of the world's top spenders on R&D. In fact, three of the five largest corporate R&D spenders showed significant decreases in their 2003 budgets: the top spender, Ford Motor, cut its budget by $200 million, and Siemens, a longtime powerhouse in research and development, decreased spending by $900 million. ¶ The picture, however, is far from being universally bleak. *Technology Review*'s innovation index, which is calculated from four key measures, shows healthy—and growing—spending by leading pharmaceutical, biotech, and computer companies. Familiar names like Pfizer, Amgen, and Nokia lead the list. But the innovation index also contains some surprises. High on the list were BMC Software and Swiss biotech firm Serono. And Volkswagen and Nissan Motor ranked, unlike most of their competitors in the auto industry, right up with Merck and Intel.

INDUSTRY'S DOLDRUMS

SPENDING ON R&D CONDUCTED BY U.S. BUSINESSES HAS DECLINED FOR THE LAST THREE YEARS IN A ROW, MIRRORING A SIMILAR MALAISE IN THE EARLY 1990S.



IN CONSTANT 1996 DOLLARS. 2003 DATA ARE PRELIMINARY. DATA FOR FEDERALLY FUNDED R&D CENTERS AND NONPROFIT ORGANIZATIONS ARE NOT SHOWN (IN 2003, THEIR COMBINED R&D PERFORMANCE TOTALLED AN ADDITIONAL $22.2 BILLION). SOURCE: NATIONAL SCIENCE FOUNDATION

Predictably, pharmaceutical and electronics companies feature prominently among the 150 top spenders, with some 28 pharma and medical-device companies and 19 electronics firms showing up. But the continued consolidation of research within some sectors is also notable. For example, Intel spent $4.36 billion last year, while its nearest rival in the semiconductor business had an R&D budget of only $1.72 billion. Even in the technologically competitive biopharmaceutical industry, one company, Pfizer, dominates, with a $7.13 billion budget; the second-ranked drug corporation spends nearly $2.2 billion less.

Of course, R&D budgets only partially reflect the state of innovation. In the following pages, *Technology Review* also profiles three corporate research projects; each tells a very different story about the challenges of commercializing radically new technologies. As you read in the profiles, business, legal, and financial factors all play key roles in determining how—and whether—new technologies move out of the lab. Together these profiles present a peek into the workings of today's corporate research labs. **DAVID ROTMAN**

THE TOP 15

AUTOMOTIVE, COMPUTER, AND PHARMACEUTICAL COMPANIES DOMINATE THE LIST OF THE COMPANIES WITH THE HIGHEST R&D EXPENDITURES.

COMPANY	COUNTRY	R&D 2003 ($MIL)	R&D PERCENT CHANGE	ABSOLUTE CHANGE IN R&D ($MIL)
FORD MOTOR	United States	$7,500	-3%	-$200
PFIZER	United States	$7,131	38%	$1,955
DAIMLERCHRYSLER	Germany	$6,689	-8%	-$600
TOYOTA MOTOR	Japan	$6,210	2%	$97
SIEMENS	Germany	$6,084	-13%	-$903
GENERAL MOTORS	United States	$5,700	-2%	-$100
MATSUSHITA ELECTRIC	Japan	$5,272	5%	$257
IBM	United States	$5,068	7%	$318
GLAXOSMITHKLINE	United Kingdom	$4,910	-4%	-$192
JOHNSON AND JOHNSON	United States	$4,684	18%	$727
SONY	Japan	$4,683	16%	$649
MICROSOFT	United States	$4,659	8%	$352
NOKIA	Finland	$4,514	23%	$850
INTEL	United States	$4,360	8%	$326
VOLKSWAGEN	Germany	$4,233	22%	$762

POLYMERS TO PIXELS

COMPANY: PHILIPS ELECTRONICS
BENEFIT: CHEAP, HIGH-QUALITY FLAT-SCREEN TVS

BY JESSICA GORMAN

PHILIPS

Electronics superstores like Best Buy are bustling right now, as holiday shoppers search for the perfect gift. Some of the big-ticket items are the most mesmerizing—row after row of 50-inch flat-screen TVs costing thousands of dollars. But in a few years, if ongoing research at Philips Electronics succeeds, stores will offer a new, cheaper option: a flat-screen TV that brings images to life with a layer of light-emitting diodes that use novel organic molecules.

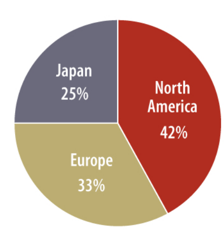
Philips, one of the world's largest makers of flat-screen plasma and liquid-crystal displays (LCDs), has spent more than a decade at its labs in Eindhoven, the Netherlands, working to perfect the polymer-based screens. The technology, says Nijs van der Vaart, the leader of the project at Eindhoven, "has so many advantages." For one thing, black is "very black," while LCD screens allow light to leak through blacked-out pixels. And unlike LCDs, the new technology allows viewing from any angle; it also eliminates the shadows that follow fast-moving objects like soccer balls. But the advantage that consumers might find most eye-catching is a price that's potentially lower than either plasma or LCD televisions'; in theory, at least, manufacturing displays out of light-emitting plastics will be far cheaper.

Philips's new type of display relies on a fundamental breakthrough in materials science. Normally, polymers don't emit light, but in 1989 physicists at the University of Cambridge developed a new type of plastic that shone brightly when sandwiched between electrodes. Philips started research on the new technology soon after. For a display manufacturer like Philips, the implications were obvious: selectively addressing small areas of the polymer layer with electricity would get those areas to selectively emit light. In other words, you could make pixels.

Philips is not without competition in trying to come up with a better flat-screen display, but it hopes to gain an edge by leveraging its expertise in

NORTH AMERICA STILL DOMINATES

BUT EUROPE AND JAPAN COMBINED ARE HOME TO MANY MORE OF THE COMPANIES WITH THE HIGHEST R&D EXPENDITURES THAN NORTH AMERICA.



BASED ON THE 150 COMPANIES SPENDING THE MOST ON R&D IN 2003. SOURCES: STANDARD AND POOR'S, *TECHNOLOGY REVIEW*

THERE'S NOT ENOUGH ART IN OUR SCHOOLS.

NO WONDER PEOPLE THINK LOUIS ARMSTRONG WAS THE FIRST MAN TO WALK ON THE MOON.

It's a long way from the Apollo Theatre to the Apollo program. And while his playing may have been "as lofty as a moon flight," as *Time* magazine once suggested, that would be as close as Louis Daniel Armstrong would ever get to taking "one small step for man."

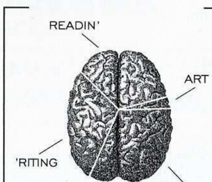
Instead of a giant leap, Louis Armstrong delivered one giant free-form crazy jazz groove for mankind.

But as the jazz musician of the 20th century, giant leaps were simply a matter of course for Satchmo. For no one has ever embodied the art form the way he did. It was he who helped make virtuoso solos a part of the vocabulary. It was he who was honored with the title "American goodwill ambassador" by the State Department. It was he who was the last jazz musician to hit #1 on the Billboard pop chart.

Armstrong left his footprints on the jazz world, wearing lace-up oxfords.

Not bad for a kid whose first experience with the trumpet was as a guest in a correctional home for wayward boys. If only today's schools were as enlightened and informed as that reformatory was.

Alas, the arts are dismissed as extravagant in today's schools. This, despite all the studies that show parents believe music and dance and art and drama make their children much better students and better people. If you feel like your kids aren't getting their fair share, make some noise. To find out how, or for more information about the benefits of arts education, please visit us on the web at AmericansForTheArts.org. Just like the great Louis Armstrong, all you need is a little brass.



There's plenty of brain to go around. Give more to art.

ART. ASK FOR MORE.

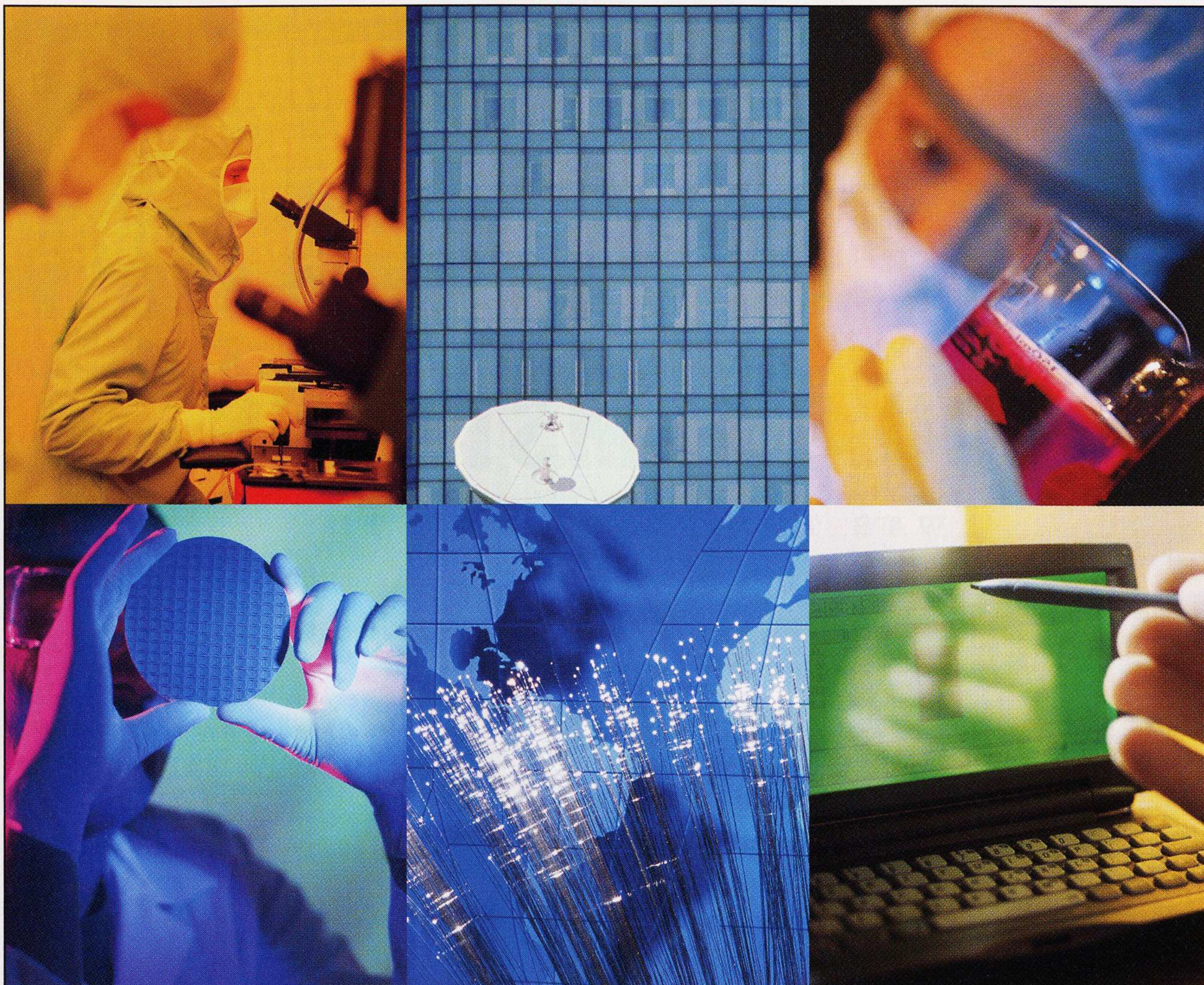
Ad Council

For more information about the importance of arts education, contact www.AmericansForTheArts.org.

Photo used with permission, Louis Armstrong Educational Foundation.

AMERICANS for the ARTS

DORIS DUKE CHARITABLE FOUNDATION



chemistry and materials science. Van der Vaart and his research colleagues are looking for further ways to improve the light-emitting properties of the polymers. They have also built a novel ink-jet printer that uses separate print heads to deposit the polymers as red, green, and blue pixels. Philips believes this printing system is potentially a cheap and versatile way to make the super-size television screens.

One problem that Philips's researchers continue to wrestle with is the light-emitting lifetime of the polymers. In particular, Philips's blue polymer fades after far less use than the roughly 20,000 hours a television needs to be able to endure. Another challenging problem is that some parts of the polymer-LED screen fade before others. And to make a 30-inch TV screen, Philips's researchers must improve the display's efficiency, so that smaller currents will elicit the needed light from the polymers.

But after more than a decade of work, the research is beginning to yield results. In 2002, the company introduced the technology in a display on an electric shaver. In 2004, Philips released a cell phone with a small polymer-LED display. Larger, higher-resolution displays will probably appear in cell phones around 2005, says van der Vaart, who is optimistic that a 30-inch or larger TV could reach stores by 2008.

In the meantime, holiday shoppers who want cheap flat-screen televisions based on brightly glowing polymers will have to wait. Perhaps an electric shaver would make a nice gift instead; you could even get one with a polymer display.

PEER-TO-PEER PHONES

COMPANY: NOKIA
BENEFIT: IMAGE SHARING ON CELL PHONES

BY PATRIC HADENIUS

Peer-to-peer computing has become an enormously popular way to share digital data, enabling, among other applications, music downloads via the now defunct sharing service Napster. Now Nokia, the Finnish telecom giant, is working to bring it to multimedia mobile phones.

NOKIA

Why is the world's largest maker of cell phones suddenly interested in the technology that made Napster a household name and an industry villain? The sale of more and more smart phones, camera phones, and game phones is driving a constant search for new applications to support them. Indeed, the killer application for all those camera phones has yet to be found—but peer-to-peer could help. With file-swapping technology, you and your friends could easily share photos you take with your phones. Or when you have a colleague on the phone, you could share a document and even edit it at the same time.

At least, that's what Nokia is betting on. With one-third of the mobile-phone market, $36.2 billion in net sales, and $6.3 billion in profit last year, Nokia is

TECHNOLOGY REVIEW'S INNOVATION INDEX

THE INNOVATION INDEX, AS CALCULATED BY TECHNOLOGY REVIEW, TAKES INTO ACCOUNT NOT ONLY THE SIZE OF A COMPANY'S R&D BUDGET BUT ALSO ITS INCREASE IN SPENDING AND THE AMOUNT SPENT IN RELATION TO SALES. NONETHELESS, THE SECOND-LARGEST R&D SPENDER, PFIZER, COMES OUT AT THE HEAD OF THE PACK.

RANK BY INNOVATION INDEX	COMPANY	INNOVATION INDEX	R&D 2003 ($MIL)	R&D PERCENT CHANGE	ABSOLUTE CHANGE IN R&D SPENDING ($MIL)	R&D AS A PERCENT OF SALES
1	PFIZER	178	$7,131	38%	$1,955	16%
2	AMGEN	149	$1,655	48%	$539	20%
3	NOKIA	146	$4,514	23%	$850	13%
4	JOHNSON and JOHNSON	141	$4,684	18%	$727	11%
5	BMC SOFTWARE	138	$586	20%	$96	41%
6	VOLKSWAGEN	138	$4,233	22%	$762	4%
7	SONY	136	$4,683	16%	$649	7%
8	MERCK (U.S.)	135	$3,178	19%	$501	14%
9	SERONO	134	$468	31%	$110	25%
10	ASTRAZENECA	134	$3,451	12%	$382	18%
11	MICROSOFT	133	$4,659	8%	$352	14%
12	ROCHE	133	$3,694	12%	$396	15%
13	NOVARTIS	133	$3,756	12%	$394	15%
14	INTEL	132	$4,360	8%	$326	14%
15	NISSAN MOTOR	129	$3,225	18%	$491	5%

THE INNOVATION INDEX IS CALCULATED BY INDEXING EACH OF THE FOUR R&D MEASURES SHOWN TO THE HIGHEST-PERFORMING COMPANY AND THEN CREATING A COMBINED, UNWEIGHTED AVERAGE. SOURCE: STANDARD AND POOR'S, *TECHNOLOGY REVIEW*

indisputably the world's leader in mobile communication. But it's an increasingly competitive business. So the pressure is on Nokia's research departments to devise cell-phone improvements that will distinguish their products from competitors'.

To help reinvigorate the company's technology, Jukka Nurminen at Nokia's research center in Helsinki, Finland, recruited Balázs Bakos at its site in Budapest to start investigating the possibilities of moving peer-to-peer from the wired world to the mobile world. Any peer-to-peer system sends information between computers with a minimum of hierarchy, using few, if any, servers and databases. So at first glance, the technology might seem a natural for the mobile world: isn't talking on the phone already a kind of peer-to-peer networking? In fact, there are plenty of servers and directories needed to connect two phones and keep a line open between them. And mobile phones have other limitations that typical wired devices don't, including far less processing power and memory, a short battery life, and limited bandwidth.

One of the first questions Nurminen and his Hungarian partner addressed was whether a typical mobile network could support a widely used file-sharing protocol called Gnutella. The experiment proved a dead end. "I think of it as an important finding," argues Nurminen, "but we saw that it didn't scale above 10,000 phones." The problem was that peer-to-peer applications use a lot of bandwidth as they hunt for information. And the demand for bandwidth multiplies rapidly as more computers join the network. On the Internet this is less of a problem, since there is plenty of bandwidth, and most service providers charge their users flat rates, regardless of the number of bits they send. But on the mobile networks, where bandwidth is limited, and the pricing is per connection and per bit sent, users need a protocol that skyrocketing traffic won't overwhelm.

So Nurminen and Bakos focused on reducing bandwidth requirements. The first step was to restrict search traffic by dividing the whole network into smaller clusters. Each phone in the network keeps a list of the images and other files stored within its cluster and can respond to queries from outside on behalf of the whole cluster. In a simulated mobile network, this approach proved ideal, enabling fast searching without sacrificing network resilience.

Having solved a key technical challenge, the researchers took their work to the company's business units. But here the project ran into a hitch: concerns about digital rights management. With the fate of Napster still fresh in everyone's mind, the business side didn't want to start promoting technology that could facilitate the exchange of copyright-protected material. Erich Hugo, Nokia's technology marketing manager, says, "The technology is still in development."

Maybe so, but if the Napster phenomenon is any indication, once potential users understand the possibilities of peer-to-peer cell phones, it might be next to impossible to go back. Peer-to-peer technology, after all, has always distinguished itself by a very strong reluctance to be controlled.

SINGLE-ELECTRON TRANSISTORS

COMPANY: TEXAS INSTRUMENTS
BENEFIT: ULTRASMALL INTEGRATED CIRCUITS

BY PETER FAIRLEY

TEXAS INSTRUMENTS

CEOs at technology firms like to boast that the intuitions of individual researchers and engineers are their companies' greatest assets. A string of recent patent filings authored by Texas Instruments electronics researcher Christoph Wasshuber shows that in some cases, at least, there's truth to that claim. By giving the 36-year-old Austrian-born engineer the flexibility to follow his instincts in designing a novel type of single-electron transistor, Texas Instruments has secured a toehold in the development of a technology that could transform semiconductor microchips in the decades to come.

In many ways, a single-electron transistor, which is turned on and off by the addition or subtraction of a lone electron, is the ultimate in semiconductor miniaturization. Not only could it allow the manufacture of powerful, ultrasmall electronic devices, but it could also slash power consumption. While exotic versions of these highly sensitive electronic switches have been around since the late 1980s, research on them has stalled because of severe problems in making them robust enough. The same property that makes them attractive, their ultrasensitivity, also makes it difficult to get them to work effectively in the real world. In particular, single-electron transistors are easily overwhelmed by background noise or signals from neighboring circuits. But Wasshuber and his collaborators at the Swiss Federal Institute of Technology in Lausanne have designed a single-electron transistor that, incorporated into standard silicon circuitry, is immune to interference.

If the innovative design works, suggests Wasshuber, it could result in ultrafast single-electron processors. What's more, Wasshuber's transistors should be compatible with standard semiconductor fabrication

processes, enabling manufacturers to push beyond conventional microchip technology without abandoning their multibillion-dollar investments in production capacity. The first uses of the single-electron transistors will likely be in memory chips and ultrasensitive electrometers for testing electrical circuits. Konstantin Likharev, a physicist at New York's Stony Brook University, estimates that a memory chip with single-electron transistors could store a terabit of data in a square centimeter of silicon, a data density about 100 times greater than that of today's best memory.

But even more important to the future of microelectronics, single-electron transistors could solve one of the gravest problems facing conventional chip technology; as more and more transistors are packed together, heat becomes harder to dissipate. Hundreds of thousands of electrons flow through a conventional transistor, and as a result, switching it on and off usually takes at least one volt. Over the next decade, chips will be jammed with billions of transistors, and the power required to switch them could literally cook the circuits. In contrast, a single-electron transistor, turned on or off by just one electron, runs cool and consumes one-tenth as much power. "If you look ahead to the end of the industry's technology road map, we're going to have 30 to 50 billion transistors on a chip," says Dennis Buss, Texas Instruments' vice president of silicon technology development. "The thought of operating those at one volt is unthinkable."

Texas Instruments hired Wasshuber in 1998 for his computer modeling expertise and set him to work on a series of near-term projects. But at night the young physicist cranked out designs of single-electron transistors like those he had worked on in graduate school. When a Texas Instruments task force scouting future technologies vital to the semiconductor industry selected single-electron transistors as one idea warranting a closer look, Wasshuber was in luck. Finally, he had the green light to pursue his hobby in the daylight hours at the lab.

Despite single-electron transistors' broad implications, however, experts who have been working on them for more than a decade caution against overenthusiasm. Likharev calls Wasshuber's ideas "clever" but wants to see proof that the new designs will work in real circuits. Then there's the challenge of manufacturing actual devices based on the designs. A single-electron transistor that operates at room temperature will require features as small as one to two nanometers across. "That's the size of molecules," notes Greg Snider, an electrical engineer at the University of Notre Dame and an expert in single-electron transistors. "The semiconductor industry is quite a ways away from doing that controllably."

Wasshuber agrees that plenty of work remains before devices using single-electron transistors show up in cell phones and desktops. And a large-scale research and development effort on the new chip technology is far more than Texas Instruments can justify funding today, given its expectation that it can continue to miniaturize conventional transistors through 2015. For the moment, Texas Instruments is salting away its patents while keeping a close eye on the emerging field. But whether Wasshuber's design for single-electron transistors proves practical or not, the company's opportunity to explore the future of microelectronics is worth the investment in turning his after-work hobby into part of his day job. TR

THE BUSINESS OF INNOVATION

WHEN FACTORS LIKE R&D GROWTH ARE TAKEN INTO ACCOUNT, THE BIOTECH, PHARMACEUTICAL, AND TECHNOLOGY SECTORS RANK HIGHLY. BUT WHEN IT COMES TO PURE BUDGET SIZE, INDUSTRIAL CONGLOMERATES AND TRANSPORTATION COMPANIES ARE TOPS.

INDUSTRY SECTOR	AVERAGE RANK BY INNOVATION INDEX	NUMBER OF COMPANIES IN THE TOP 2003 R&D SPENDERS	AVERAGE R&D 2003 ($MIL)	AVERAGE R&D PERCENT CHANGE	AVERAGE ABSOLUTE CHANGE IN R&D SPENDING ($MIL)	AVERAGE R&D AS A PERCENT OF SALES
Biotechnology	22	3	$917	28%	$225	21%
Computer software	41	7	$1,341	11%	$111	18%
Pharmaceuticals/medical devices	48	28	$2,045	9%	$176	14%
Semiconductors	50	10	$1,318	1%	$41	22%
Transportation	72	26	$2,273	5%	$72	5%
Computer hardware	81	9	$2,251	-0.4%	$4	7%
Heavy machinery	84	5	$663	9%	$58	5%
Electronics/electrical	90	19	$1,616	0.1%	$11	6%
Aerospace and defense	93	8	$1,369	1%	$29	6%
Telecommunications	100	13	$2,156	-10%	$(269)	11%
Chemicals	104	10	$1,083	-1%	$(19)	6%
Consumer products	108	5	$1,043	2%	$6	2%
Industrial conglomerates	109	4	$2,490	-3%	$(241)	4%
Energy	112	3	$586	2%	$2	2%

SOURCE: STANDARD & POOR'S, *TECHNOLOGY REVIEW*

CORPORATE R&D SCORECARD 2004

DESPITE THE DOWNTURN in U.S. business research-and-development spending, a few industry sectors saw R&D grow by leaps and bounds last year. The three biotech companies on this list of the top 150 spenders increased their budgets by an average of 28 percent, easily outpacing every other sector. In three other industry sectors, R&D budgets expanded by around 10 percent: computer software, pharmaceuticals/medical devices, and heavy machinery. Some technology sectors, however, continued to retrench. R&D expenditures by telecom companies on the list fell by 10 percent, continuing the trend of severe decreases over the last few years. R&D spending by Lucent Technologies, for example, fell 36 percent. Computer hardware companies, too, saw spending stagnate, with a .4 percent overall decline. But life sciences firms predominated among fast-growing R&D spenders. Amgen, Pfizer, and Serono each had research budgets that skyrocketed by about one-half to one-third last year. **STACY LAWRENCE**

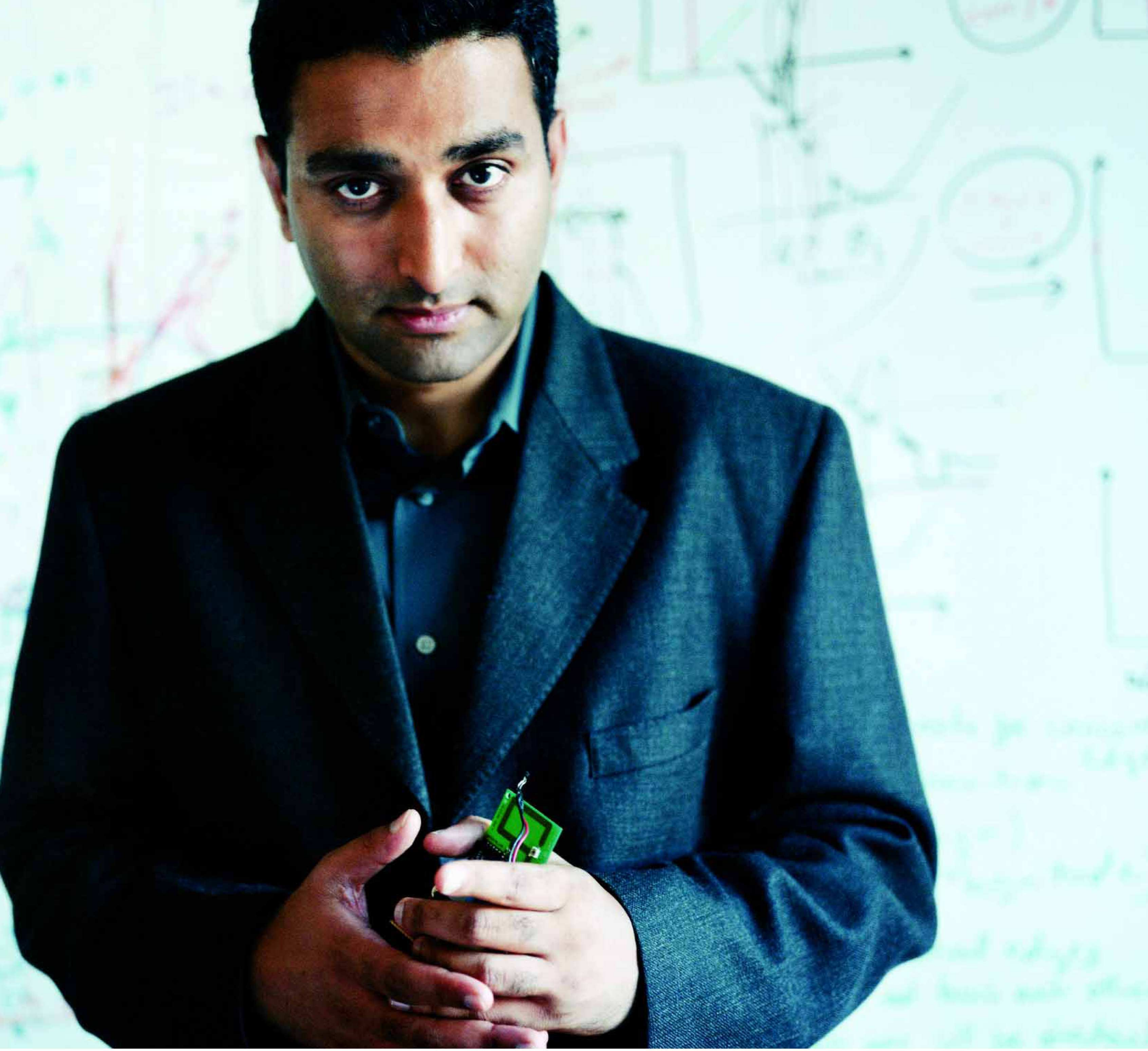
	COUNTRY	R&D SPENDING 2003* ($MIL)	R&D SPENDING PERCENT CHANGE	ABSOLUTE CHANGE IN R&D ($MIL)	R&D AS A % OF SALES	R&D PER EMPLOYEE	INNOVATION INDEX RANK	RESEARCH FOCUS
AEROSPACE/DEFENSE								
Lockheed Martin	United States	$903	9%	$73	3%	$6,946	87	Aircraft, ships, electronics, energy systems, engineering
Raytheon	United States	$487	8%	$38	3%	$6,268	98	Missile defense, intelligence, security
BAE Systems	United Kingdom	$3,013	7%	$194	20%	$44,055	16	Aircraft, ships, submarines, communications, electronics, guided weapons
EADS	Netherlands	$2,628	4%	$112	7%	$24,082	53	Materials, engineering, electronics, sensors, information technology
Boeing	United States	$1,651	1%	$12	3%	$10,516	100	Aircraft, electronics, airport technology, engineering, energy systems
Honeywell International	United States	$751	-1%	-$6	3%	$6,954	123	Security, sensors, environmental control
Rolls-Royce	United Kingdom	$494	-5%	-$28	5%	$13,693	133	Aerospace, ships, energy systems
United Technologies	United States	$1,027	-14%	-$164	3%	$5,052	142	Energy systems, environmental control, engineering, engines
Average		***$1,369***	***1%***	***$29***	***6%***	***$14,696***	***94***	
BIOTECHNOLOGY								
Amgen	United States	$1,655	48%	$539	20%	$128,326	2	Cancer biology, inflammation, metabolic disorders, neurology, hematology
Serono	Switzerland	$468	31%	$110	25%	$102,202	9	Reproductive health, neurology, dermatology, growth and metabolism
Genentech	United States	$626	5%	$27	19%	$100,626	57	Oncology, immunology, vascular biology
Average		***$917***	***28%***	***$225***	***21%***	***$110,385***	***23***	
CHEMICALS								
DuPont	United States	$1,349	7%	$85	5%	$16,654	77	Materials, chemicals, biology
Syngenta	Switzerland	$727	4%	$30	11%	$33,882	78	Crop protection, genomics, crop genetics, chemicals
Sumitomo Chemical	Japan	$684	3%	$22	6%	$35,953	97	Nanoscale materials, fuel cells, genomics, proteomics, chemistry
Solvay	Belgium	$485	2%	$8	5%	$17,084	110	Pharmaceuticals, chemicals, plastics
BASF	Germany	$1,326	-3%	-$37	3%	$15,218	119	Biotechnology, genetic engineering, chemistry, nanotechnology
Akzo Nobel	Netherlands	$1,065	-3%	-$30	7%	$16,486	111	Pharmaceuticals, coatings, chemicals
Mitsubishi Chemical	Japan	$806	-3%	-$23	5%	$24,051	126	Petrochemicals, performance products, functional materials, health care

	COUNTRY	R&D SPENDING 2003* ($MIL)	R&D SPENDING PERCENT CHANGE	ABSOLUTE CHANGE IN R&D ($MIL)	R&D AS A % OF SALES	R&D PER EM-PLOYEE	INNO-VATION INDEX RANK	RESEARCH FOCUS
Monsanto	United States	$510	-3%	-$17	10%	$38,636	109	Crop protection, genomics, crop genetics, chemicals
Bayer	Germany	$2,898	-5%	-$142	8%	$25,116	85	Health care, crop protection, materials, information technology
Dow Chemical	United States	$981	-8%	-$85	3%	$21,155	136	Chemicals, plastics, crop science, energy
Average		***$1,083***	***-1%***	***-$19***	***6%***	***$24,423***	***105***	
COMPUTER HARDWARE								
Hewlett-Packard	United States	$3,652	10%	$340	5%	$25,718	24	Internet systems, wireless communication, security, privacy, printing
IBM	United States	$5,068	7%	$318	6%	$15,874	19	Deep computing, displays, e-commerce, semiconductors, storage
Apple Computer	United States	$471	6%	$25	8%	$34,719	91	Hardware, operating systems, multimedia applications
Seiko Epson	Japan	$824	6%	$43	6%	$9,701	88	Printers, projection, electronic components, optics
Toshiba	Japan	$3,065	2%	$48	6%	$19,001	63	Film, optics, wireless communication, transistors
Sun Microsystems	United States	$1,837	0%	$5	16%	$50,886	58	Business PDA applications, device networks, speech technology, Java
EMC	United States	$718	-8%	-$63	12%	$35,924	121	Storage
Fujitsu	Japan	$2,284	-12%	-$317	5%	$14,623	135	Ubiquitous computing, security, human interfaces, natural-language processing
NEC	Japan	$2,336	-13%	-$360	5%	$16,292	138	Banking systems, e-government systems, optical and IP networks, device networks
Average		***$2,251***	***-0.4%***	***$4***	***8%***	***$24,749***	***82***	
COMPUTER SOFTWARE								
Electronic Arts	United States	$511	27%	$110	17%	$106,429	20	Mobile gaming, motion capture, 3-D face- and body-rendering technologies
BMC Software	United States	$586	20%	$96	41%	$91,165	5	Storage, security, service provider solutions, enterprise management, Linux
SAP	Germany	$1,193	9%	$102	14%	$41,014	45	Business process applications, e-business solutions
Oracle	United States	$1,278	8%	$98	13%	$30,678	48	Grid computing, Web services, Java, Linux, mobile software, RFID/sensor services
Microsoft	United States	$4,659	8%	$352	14%	$84,709	11	Multimedia, search, knowledge management, security, machine learning
Automatic Data Processing	United States	$499	5%	$24	7%	$12,175	95	Data processing, outsourced services
Computer Associates	United States	$662	0%	-$2	20%	$43,268	64	Enterprise software, extensible systems, open-source software, access, security
Average		***$1,341***	***11%***	***$111***	***18%***	***$58,491***	***41***	
CONSUMER PRODUCTS								
Altria Group	United States	$762	11%	$76	1%	$4,618	89	Food safety, nutrition, obesity, health and wellness products
Procter and Gamble	United States	$1,665	4%	$64	4%	$16,990	83	Fats and oils, absorbent structures and materials, perfumes and odor management
L'Oréal	France	$576	3%	$14	3%	$11,412	112	Polymers, hair color, sunscreens, emulsifiers, perfumes, body care, sun protection
Nestlé	Switzerland	$934	0%	-$2	1%	$3,690	125	Packaging materials, infant nutrition, clinical nutrition, performance nutrition
Unilever Group	United Kingdom	$1,279	-9%	-$121	2%	$5,328	137	Spreads, nutrition, culinary products, hair care, deodorants, household care, skin care
Average		***$1,043***	***2%***	***$6***	***2%***	***$8,408***	***109***	
ELECTRONICS/ELECTRICAL								
Sony	Japan	$4,683	16%	$649	7%	$28,905	7	Semiconductors, robotics, nanomaterials, fuel cells, networking, devices
Sumitomo Electric	Japan	$503	14%	$60	4%	$5,755	79	Information technology, communications, electronics, automotive, materials, energy
Pioneer	Japan	$469	13%	$55	7%	$12,887	66	Optical discs, devices, displays, audio technology, information technology
Canon	Japan	$2,359	11%	$232	8%	$22,996	31	Cameras, sensors, optics, nanomaterials
Ricoh	Japan	$842	11%	$82	5%	$11,513	74	Cameras, printers
Fuji Photo Film	Japan	$1,578	9%	$129	7%	$21,562	61	Digital imaging systems, recording/storage media, film and imaging systems
Matsushita Electric	Japan	$5,272	5%	$257	8%	$18,148	17	Display technology, multimedia, electronic products
Schneider Electric	France	$593	5%	$26	6%	$7,985	99	Electrical distribution, automation and control
Sanyo Electric	Japan	$1,140	4%	$40	5%	$13,840	94	Solar cells, photonics, home networks, 3-D image data processing, fuel cells, robotics
Sharp	Japan	$1,263	3%	$42	6%	$27,363	86	LCDs, 3-D imaging displays, optoelectronics
Hitachi	Japan	$3,384	-1%	-$49	4%	$11,028	75	Nanoelectronics, home networks, bioinformatics, mobile communications
Eastman Kodak	United States	$750	-2%	-$12	6%	$11,737	116	Imaging, sensors, wireless networks, photographic media
Emerson Electric	United States	$514	-3%	-$16	4%	$4,817	129	Communications, software, electronics
Matsushita Electric Works	Japan	$481	-4%	-$22	4%	$10,101	131	Materials, software, optical switches, lighting
Xerox	United States	$868	-5%	-$49	6%	$14,206	127	Microelectromechanical systems (MEMS), optoelectronics, integrated systems
Agilent Technologies	United States	$1,051	-10%	-$118	17%	$36,241	102	Communications, molecular biology, nanoscale science, photonics, sensors
Philips Electronics	Netherlands	$3,142	-14%	-$526	9%	$19,108	130	Display technology, lenses, device networks, semiconductors, batteries
Alstom	France	$568	-24%	-$179	3%	$7,393	148	Information and communication technologies, power electronics systems, materials
Mitsubishi Electric	Japan	$1,242	-24%	-$391	4%	$12,551	147	Internet computing, advanced graphics, digital TV, multimedia, communications
Average		***$1,616***	***0.1%***	***$11***	***6%***	***$15,692***	***90***	

	COUNTRY	R&D SPENDING 2003* ($MIL)	R&D SPENDING PERCENT CHANGE	ABSOLUTE CHANGE IN R&D ($MIL)	R&D AS A % OF SALES	R&D PER EM-PLOYEE	INNO-VATION INDEX RANK	RESEARCH FOCUS
ENERGY								
Royal Dutch/Shell	Netherlands	$584	24%	$112	0%	$4,908	59	Chemicals, energy
Exxon Mobil	United States	$618	-2%	-$13	0%	$6,999	134	3-D seismic technology, drilling, energy
Schlumberger	Netherlands Antilles	$556	-14%	-$94	4%	$7,222	144	Drilling, energy
Average		***$586***	***2%***	***$2***	***2%***	***$6,376***	***112***	
HEAVY MACHINERY								
Volvo	Sweden	$898	16%	$126	4%	$12,281	62	Transportation, telematics, Internet applications, databases, ergonomics
ABB	Switzerland	$613	11%	$63	3%	$5,263	84	Nanotechnology, microelectromechanical systems (MEMS), wireless applications
John Deere	United States	$577	9%	$50	4%	$13,357	90	Engines, agricultural equipment
ITT	United States	$559	8%	$40	10%	$14,344	76	Electronic interconnects and switches, defense communications, optoelectronics
Caterpillar	United States	$669	2%	$13	3%	$9,672	114	Fuel cells, machines, engines, power generation
Average		***$663***	***9%***	***$58***	***5%***	***$10,983***	***85***	
INDUSTRIAL CONGLOMERATES								
3M	United States	$1,102	3%	$32	6%	$16,430	92	Light management, film solutions, fuel cells, lighting products
Tyco International	Bermuda	$671	3%	$19	2%	$2,593	115	Fire and building products, flow control, valves, optics
General Electric	United States	$2,103	-5%	-$112	2%	$6,895	124	Ceramics, energy, environmental, imaging, photonics, nanotechnology
Siemens	Germany	$6,084	-13%	-$903	7%	$14,589	108	Materials, light, imaging, robotics, user interfaces, logistics
Average		***$2,490***	***-3%***	***-$241***	***4%***	***$10,127***	***110***	
PHARMACEUTICALS/MEDICAL DEVICES								
Pfizer	United States	$7,131	38%	$1,955	16%	$58,451	1	18 therapeutic areas, including oncology, cardiovascular, and central nervous system
Merck	United States	$3,178	19%	$501	14%	$50,286	8	13 therapeutic areas, including arthritis, asthma, cancer, cardiovascular, diabetes
Guidant	United States	$518	18%	$81	14%	$43,200	34	Imaging and diagnostics, vascular, bioabsorbable materials
Johnson and Johnson	United States	$4,684	18%	$727	11%	$42,351	4	9 therapeutic areas, including central nervous system, gastrointestinal
Fujisawa Pharmaceutical	Japan	$670	18%	$102	19%	$85,537	26	Transplantation, dermatology, stroke, neurodegenerative, diabetes
Eisai	Japan	$628	16%	$85	14%	$81,582	39	Immunology, endocrinology, gastroenterology, neurology, cardiology, pulmonology
Medtronic	United States	$852	14%	$102	9%	$27,557	54	Cardiac rhythm management, neurology, cardiac surgery, vascular
AstraZeneca	United Kingdom	$3,451	12%	$382	18%	$55,751	10	Cardiovascular, gastrointestinal, infection, neuroscience, oncology, respiratory
Roche	Switzerland	$3,694	12%	$396	15%	$58,305	12	12 therapeutic areas, including anemia, virology, infectious diseases, genito-urinary
Novartis	Switzerland	$3,756	12%	$394	15%	$47,822	13	10 therapeutic areas, including metabolic, ophthalmics, oncology
Altana	Germany	$495	12%	$51	15%	$47,539	49	Gastrointestinal, respiratory
Abbott Laboratories	United States	$1,733	11%	$172	9%	$24,016	42	Infectious diseases, cardiovascular, oncology
Baxter International	United States	$553	10%	$52	6%	$10,780	81	Stem cells, biomaterials
Daiichi Pharmaceutical	Japan	$553	10%	$50	19%	$74,896	41	Infectious diseases, cancer, cardiovascular, rheumatology, ophthalmology
Eli Lilly	United States	$2,350	9%	$201	19%	$50,980	21	Diabetes, genito-urinary, central nervous system
Sanofi-Synthelabo	France	$1,580	8%	$118	16%	$47,756	33	Cardiovascular, central nervous system, oncology, internal medicine
Yamanouchi Pharmaceutical	Japan	$638	5%	$29	14%	$70,387	68	Adult and geriatric diseases
Mitsubishi Pharma	Japan	$460	5%	$21	21%	$75,121	51	Alzheimer's, cardiovascular, diabetes, reproductive health, asthma
Takeda Chemical	Japan	$1,180	4%	$49	12%	$80,870	65	Cardiovascular, obesity, diabetes, metabolic
Schering-Plough	United States	$1,469	3%	$44	18%	$48,164	47	Infectious diseases, respiratory, arthritis, oncology, cardiovascular
Bristol-Myers Squibb	United States	$2,279	3%	$61	11%	$51,795	56	Alzheimer's, oncology, diabetes, hepatitis, HIV/AIDS, obesity, central nervous system
Novo Nordisk	Denmark	$677	1%	$9	16%	$36,077	73	Diabetes, hemophilia
Wyeth	United States	$2,094	1%	$13	13%	$39,964	60	Women's health, cardiovascular, musculoskeletal, transplantation and immunology
Sankyo	Japan	$789	0%	$1	15%	$68,515	82	Cardiovascular
Merck	Germany	$726	-1%	-$4	8%	$21,222	103	Women's health, respiratory diseases, cardiovascular
Schering	Germany	$1,109	-2%	-$28	19%	$41,768	67	Gynecology and andrology, diagnostics and radiopharmaceuticals, dermatology
GlaxoSmithKline	United Kingdom	$4,910	-4%	-$192	13%	$47,590	37	Cardiovascular, infectious diseases, gastrointestinal, oncology, respiratory
Aventis	France	$3,511	-15%	-$596	16%	$46,458	104	Diabetes, asthma, multiple sclerosis
Average		***$1,988***	***8%***	***$171***	***14%***	***$51,241***	***46***	
SEMICONDUCTORS								
STMicroelectronics	Netherlands	$1,238	21%	$216	17%	$27,090	18	Solar cells, nanotechnology, microelectronics, semiconductors
Micron Technology	United States	$656	17%	$95	21%	$39,542	23	Semiconductors, image sensors

	COUNTRY	R&D SPENDING 2003* ($MIL)	R&D SPENDING PERCENT CHANGE	ABSOLUTE CHANGE IN R&D ($MIL)	R&D AS A % OF SALES	R&D PER EM-PLOYEE	INNO-VATION INDEX RANK	RESEARCH FOCUS
Intel	United States	$4,360	8%	$326	14%	$54,705	14	Microprocessors, silicon, manufacturing, photonics, networking
Texas Instruments	United States	$1,725	7%	$107	18%	$50,507	32	Mobile-device semiconductors
Advanced Micro Devices	United States	$852	4%	$36	24%	$59,586	36	Microprocessors, flash memory devices, low-power processors
Infineon Technologies	Germany	$1,307	3%	$35	18%	$41,477	52	Nanotechnology, photonics, high-frequency circuits, electronic biosensors
Freescale Semiconductor	United States	$1,005	1%	$12	21%	$43,696	55	Semiconductors, platforms, process technology
Broadcom	United States	$653	-9%	-$61	41%	$239,412	29	Semiconductors for broadband communications and networking
Applied Materials	United States	$921	-13%	-$132	21%	$76,400	101	Semiconductor wafer fabrication equipment
Agere Systems	United States	$467	-33%	-$226	25%	$68,676	139	Integrated circuits for wireless data, high-density storage
Average		***$1,318***	***1%***	***$41***	***22%***	***$70,109***	***50***	
TELECOMMUNICATIONS								
Nokia	Finland	$4,514	23%	$850	13%	$87,899	3	4G wireless, CDMA, messaging, radio, Semantic Web, device networks
Qualcomm	United States	$523	16%	$72	13%	$70,712	43	CDMA, digital wireless communications products and services
Motorola	United States	$3,771	0%	$17	14%	$42,852	30	Broadband, imaging, multimedia, microminiaturization, portable energy
Deutsche Telekom	Germany	$1,081	0%	$1,081	2%	$4,348	118	Optical networks, broadband
NTT DoCoMo	Japan	$1,133	-1%	-$16	2%	$53,354	122	Electromagnetic compatibility, high-temperature superconductors, 4G wireless
Ericsson	Sweden	$3,570	-7%	-$289	23%	$69,207	46	4G network infrastructure, access equipment and terminals
Cisco Systems	United States	$3,131	-9%	-$317	17%	$92,088	80	Home networking, optical, IP telephony, network security, wireless LAN
NTT	Japan	$3,230	-10%	-$374	3%	$15,733	128	Ubiquitous networking based on optical communication technology
BT Group	United Kingdom	$588	-12%	-$81	2%	$5,881	143	Wireless and satellite broadband, next-generation broadband
France Telecom	France	$574	-17%	-$118	1%	$2,626	145	Speech and sound, multimedia, distributed architectures, optical technology
Alcatel	France	$1,913	-28%	-$760	13%	$31,621	146	Mobile communications, fixed networks, optical networks, enterprise solutions
Lucent Technologies	United States	$1,488	-36%	-$822	18%	$43,130	149	Optical networks, wireless networks, network applications, nanotechnology
Nortel Networks**	Canada	$2,516	-36%	-$1,395	20%	$68,078	150	Photonics, DWDM, optical Ethernet, IP VPNs, 3G wireless
Average		***$2,156***	***-9%***	***-$166***	***11%***	***$45,195***	***100***	
TRANSPORTATION								
Suzuki Motor	Japan	$690	25%	$140	3%	$17,920	40	Energy and environmental technologies, electronic communication/control
Volkswagen	Germany	$4,233	22%	$762	4%	$12,568	6	Fuel cells, hybrid engines, diesel engines
Nissan Motor	Japan	$3,225	18%	$491	5%	$27,021	15	Ultralow-emissions vehicles, active headrests, curtain air bags, fuel cells
Delphi	United States	$2,000	18%	$300	7%	$10,526	27	Fuel cells, multimedia, controlled suspension, diesel engines, telematics
Denso	Japan	$1,956	18%	$292	8%	$20,491	25	Semiconductors, telecommunications, controller logics, energy
Peugeot Citroën	France	$2,519	12%	$280	4%	$12,600	35	Multiplexing, electronic stability, fuel cells, hydrogen engines
Yamaha Motor	Japan	$571	12%	$62	6%	$16,953	72	High-performance engines
Aisin Seiki	Japan	$811	11%	$82	6%	$17,027	71	Electric vehicles, intelligent transport systems, ultralow-temp refrigeration
Johnson Controls	United States	$484	10%	$45	2%	$4,102	96	Interiors, batteries, controls
Renault	France	$1,492	9%	$120	3%	$10,628	69	Hybrid engines, diesel engines
BMW	Germany	$2,577	7%	$162	5%	$24,693	50	Diesel engines, transmission, lightweight chassis, smart air bags
Bridgestone	Japan	$646	4%	$26	3%	$5,940	105	Nanotechnology, materials, lightweight and low-resistance tires
Honda Motor	Japan	$4,086	3%	$110	6%	$31,051	38	Hybrid engines, low-emission engines, robotics, fuel cells
Toyota Motor	Japan	$6,210	2%	$97	4%	$23,486	22	Electromechanics, environmental engineering
Continental	Germany	$598	1%	$8	4%	$8,690	113	EService centers, flight crew management systems
Michelin	France	$853	1%	$8	5%	$6,706	106	Tires, suspension system, electronics system
Visteon	United States	$903	0%	$1	5%	$12,542	107	Telematics, multimedia, chassis, climate control, engines
Mazda Motor	Japan	$799	0%	$0	3%	$22,432	120	Fuel cells, hydrogen engines, electric engines, smart air bags
Fiat	Italy	$2,098	0%	-$1	4%	$12,929	93	Telematics, multimedia, chassis, climate control, engines
General Motors	United States	$5,700	-2%	-$100	3%	$17,485	44	Fuel cells, low-emissions vehicles, sensors, control systems
Valeo	France	$677	-2%	-$16	6%	$9,929	117	Air conditioning, aromatherapy diffuser, pollution sensor
Ford Motor	United States	$7,500	-3%	-$200	5%	$22,899	28	Fuel cells, hydrogen engines, electronics, emissions control, diesel engines
Fuji Heavy Industries	Japan	$524	-4%	-$23	4%	$19,187	132	Diagnostic systems, aerospace, diesel engines
DaimlerChrysler	Germany	$6,689	-8%	-$600	4%	$18,474	70	Fuel cells, energy, traffic safety, CO_2 reduction, night vision systems
Mitsubishi Motors	Japan	$627	-12%	-$83	3%	$14,370	141	Fuel cells, hybrid engines
Faurecia	France	$639	-14%	-$100	5%	$10,727	140	Pedestrian detection, pollution control, materials
Average		***$2,273***	***5%***	***$72***	***5%***	***$15,822***	***72***	

* BASED ON DATA FOR MOST RECENT FISCAL YEAR ENDED AS OF MAY 31, 2004. ** BASED ON DATA FOR FISCAL YEAR ENDING DECEMBER 31, 2002. SOURCES: STANDARD AND POOR'S, COMPANY WEBSITES, *TECHNOLOGY REVIEW*

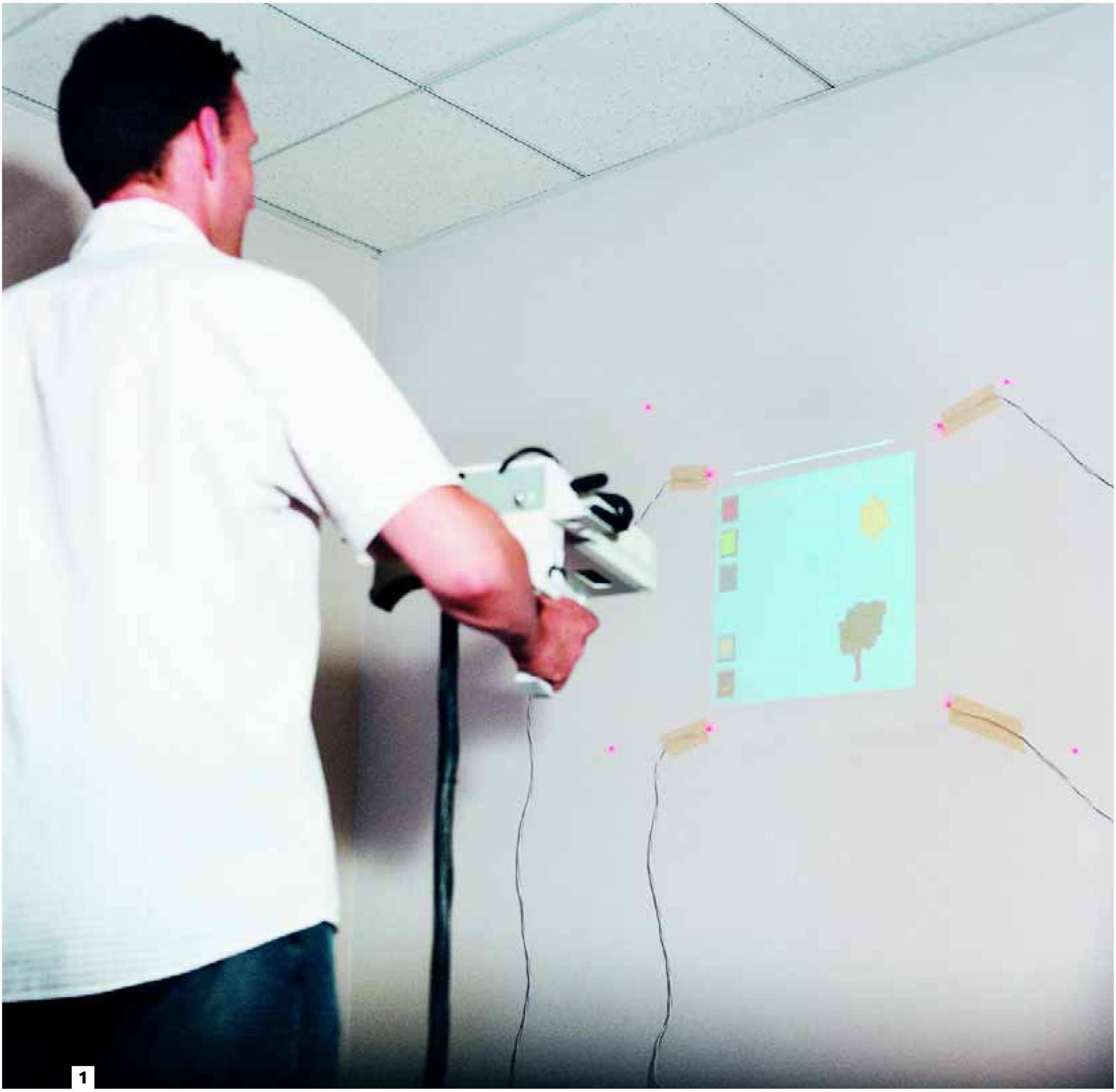


DEMO

PORTABLE PROJECTORS

Sick of squinting at the minuscule display on your cell phone or PDA? **Ramesh Raskar** might have a solution: tiny built-in projectors that turn virtually any handy surface into a display as big as you want it to be.
PHOTOGRAPHS BY KATHLEEN DOOHER

CHANCES ARE YOU can't remember the last time you hauled a projector out of the attic to look at slides or movies. But, says Ramesh Raskar, you may soon carry one with you everywhere you go. Raskar, a research scientist at Cambridge, MA's Mitsubishi Electric Research Laboratories, sees tiny projectors as the solution to one of the fundamental problems with our ever shrinking cell phones, PDAs, digital cameras, and other portable devices. The gizmos carry more and more of our data, but they are running out of room to display it to us. Build a tiny projector into each of those devices, though, and the world becomes your display. Raskar's team has developed hardware and software that can project digital images onto whatever surface is handy—the wall, say, or a desktop—and make them look good even if the impromptu screen isn't nice and smooth. And "once you buy into this notion that people would like to have this kind of an attachment," he asks, "what will they do beyond just looking at those images?" Raskar envisions projectors as the heart of a whole new way of interacting with the world, and he shared his vision with *Technology Review* senior editor Rebecca Zacks.



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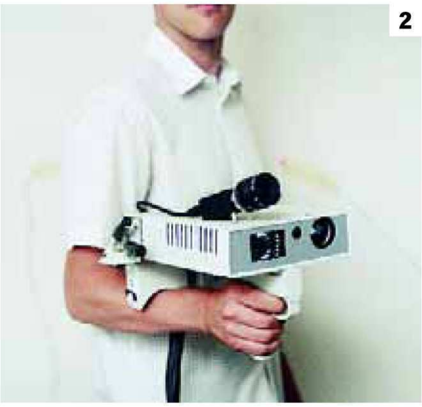

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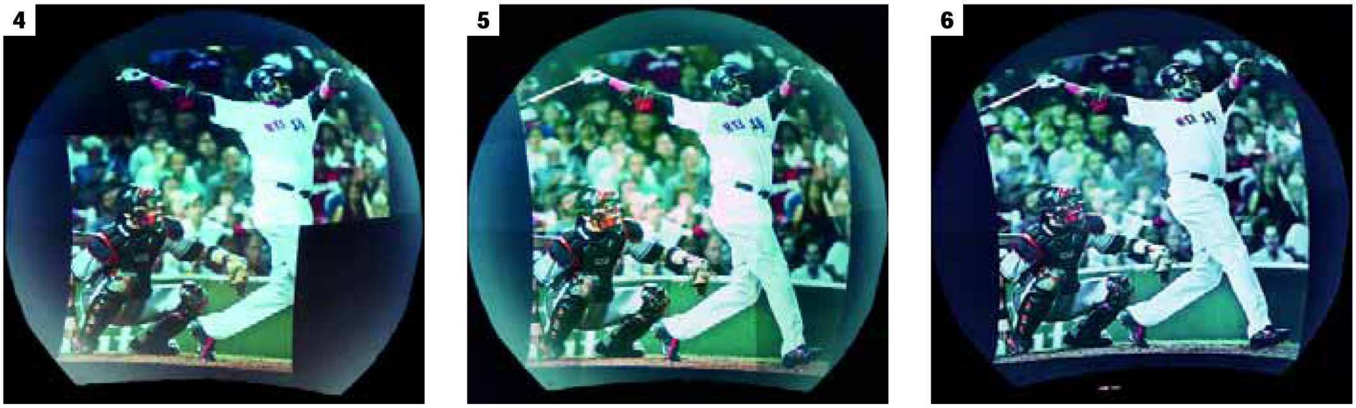
1-2. AIMING AT PORTABILITY. In a dimly lit lab, Raskar describes his vision of pencil-size projectors that are standard components in mobile devices. Then Jeroen van Baar, who along with Paul Deitz and Paul Beardsley works with Raskar on the project, picks up one of the team's prototypes. It's bigger than a pencil, to be sure, but the researchers are confident they will be able to shrink it down. Van Baar takes aim at a spot in the middle of four red lights taped to the wall. As the projector beams out a video game, four lasers, two on each side of the device, shine red dots onto the wall just beyond each corner of the projected image. A camera atop the device, Raskar explains, "is looking at all eight lights and finding the relationship between the wall and the projector." That way, the computer can adjust the image on the fly to keep it stable even as van Baar moves his hand to point and click. In the future, Beardsley believes, the system will use landmarks such as cracks or grout lines for reference, eliminating the need for the taped-on markers.

3



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3. SHARED VISION. Projecting an image on a blank white wall is one thing, Raskar says, but if people are using projectors all the time, "it might be on a nonplanar surface; it might be on a curved surface; it might be on a surface that's part red and part white, and you want to compensate for all those issues." What's more, people might want to combine the power of their small individual projectors to make bigger, brighter images. As he talks, van Baar powers up a computer attached to four projectors, all aimed at a curved screen a meter and a half across. Say, for instance, that four friends want to use their projector-equipped mobile devices to watch a baseball game, Raskar says. They'd simply aim them roughly at whatever surface is handy, he says, "just click one button, and they all start talking to each other and figure out their geometric configuration, and you see a nice big display." To illustrate, van Baar turns on the projectors one by one. As they beam out a test pattern, attached cameras and sophisticated algorithms enable the computer to figure out which projector is aimed where and which piece of the picture it should project; the computer also corrects for the curvature and color of the surface so that the image doesn't look distorted.

4-6. GREAT COMPENSATION. The last step is to compensate for the fact that the projectors' images overlap, making some areas brighter and some dimmer. "We can find exactly which two or three or four pixels overlap with each other," van Baar says, "and we can adjust correspondingly."

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7. PLAYING TAG. While bringing projectors, cameras, and wireless communication tools together could enable a host of consumer applications beyond game playing and video watching, Raskar says, even more interesting applications become possible if you throw in one more technology: radio frequency identification. RFID is now being adopted in a number of industries; in retail it's used to track products from manufacturers to stockrooms to store shelves. Raskar leads the way to a nearby conference room, where a metal bookcase has been stacked with boxes to imitate a storeroom. Each box is outfitted with a souped-up RFID tag attached via wires to a tiny photosensor that pokes through the front.

8-9. SUPER SCANNER. The photosensor, Raskar says, allows a user—a stock manager, say—to scan all the boxes at once and get an instant visual depiction of information associated with their RFID tags. (As in other RFID systems, that information is stored in an online database accessed wirelessly by the reader.) With a conventional RFID reader, finding out, say, which of a group of products have expired is difficult. That's because the reader isn't able to give specific location information; you can get the IDs off all the tags in a one- to two-meter radius, Raskar says, but if you want to know something about a specific one, "you don't know where exactly it is." Raskar's scanner—an RFID reader equipped with a projector—starts by projecting a series of vertical and horizontal lines of various thicknesses onto the shelf. By interpreting the pattern of illumination and darkness registered by its photosensor, each tag can determine its precise location. It then radios that information back to the reader.

10. AT A GLANCE. Once it knows where all the tags are, the reader looks up product information in the online database, then projects the relevant data right onto the boxes. In this case, Raskar says, a stock manager could see at a glance which products had expired and which were still okay. Or a consumer might use the system to find just what he wanted in a supermarket aisle. "Say I'm allergic to nuts, and I want low calorie, and I want something with fruits," Raskar says. "It would take me forever to search through the whole cereal aisle, but I can just aim my projector at this rack." Of course, he admits, it might take time before broad retail industries are willing to invest the extra penny per tag that it costs to add photosensors to regular RFID tags. "More-critical applications would use them first," he says. One example: hospitals hoping to avoid the medication errors that happen when busy staffers grab the wrong bottles out of cabinets. A projector-based system, Raskar says, could instantly light up just the right bottle. TR

10

Modifying GM Food Perception

BY ERIKA JONIETZ | Photograph by Steve Double

TECHNOLOGY REVIEW: After almost six years in which no genetically modified food or crop had been approved for sale in Europe, a few varieties of corn finally made it through the regulatory process this year. Where do things stand now?

SIMON BARBER: There is a complete regulatory framework in place for assessment and approval of genetically modified plants that are going to be grown or imported for food or food ingredients or animal feed. We have seen two approvals through that process for imports for food and animal-feed use of maize, for instance. So that system seems to be beginning to work. Getting approvals to grow new GM crops here, that's a different matter. That doesn't seem to be moving yet.

TR: Why not? Isn't there a process to approve new GM crops for cultivation?

BARBER: The framework is there. What is under discussion, though, is the concept of coexistence: once a crop has approval, how can I, as a farmer, choose to grow one of these varieties while minimizing any pollen and gene movement into my neighbor's crops? At the moment, I don't think we anticipate having new EU legislation on coexistence; we see the European Commission having its guidelines and then the member states making their own legislation around those guidelines. Some member states are developing their rules in a way that might well prohibit their farmers from ever choosing genetically modified seed, but others are being more pragmatic. The fact that the coexistence rules are in development doesn't give a very strong incentive for people to go for authorization to cultivate just at the moment.

TR: Why have European consumers been so wary about GM foods?

BARBER: There are groups that have made a huge amount of noise about it. They raise the question of the precautionary principle and say that we're not absolutely certain of safety—which actually we can say about everything. If we're honest, no science will say that anything is 100 percent safe. But there have been food scares here, such as mad cow, which means that our citizens are concerned about the safety of their food supply. There isn't an awful lot of what I would call very balanced debate; the debate tends to be very antagonistic, so you would have people very much "for" talking to people very much "against." If people don't have things explained to them well, there's room there for them to have concerns, and they're legitimate concerns.

TR: Has the European biotech industry done its share to explain the technology?

BARBER: They have recently made more efforts in that direction, but at the outset perhaps not as much as they ought. But it's not just the job of the industry. If you look at the industry, it's very small compared to the others that it supports. Plant variety developers and people who produce seed—that's our industry—support the farmers, which is a larger industry; the farmers then support food processors, and the value gets bigger and bigger. At the top, one U.K. supermarket chain probably has the same annual turnover as the whole international seed trade. So in some ways, we are a limited resource to be able to teach everybody in the world about modern biology and its uses. It's something that I think everybody has to be involved in. It's easy for people, once this had become an issue, to say, well, industry didn't do a good job, but before anything can be imported into Europe and used as

SIMON BARBER

POSITION: Director of the Plant Biotechnology Unit at EuropaBio, the European biotech industry association

ISSUE: Approval of genetically modified foods in Europe. Europeans have been far more nervous about the safety of GM foods than North Americans, essentially halting the approval of new varieties since 1998. Are skittish regulators and consumers finally warming up to the technology?

PERSONAL POINT OF IMPACT: Helped develop Canada's regulatory system for GM plants and worked at the Organization for Economic Co-Operation and Development on biotechnology and regulatory harmonization. Currently leads EuropaBio's efforts to inform regulators and policymakers about agricultural biotechnology and present industry views on policy issues.

animal feed or as an ingredient as food for us humans, it had to go through a safety approval process. The governments of the EU and the EU itself have institutions that did all this. Well, how were they explaining to their citizens what was going on? It's something that has to be shared across the board.

TR: But biotech companies would seem to have the most to gain from consumer acceptance of GM foods, so shouldn't they bear most of the educational responsibility?

BARBER: They should bear some responsibility, and in more recent years, they have put effort into this. There is something called Agricultural Biotechnology in Europe, which is a program that some of the companies have put money into to try to provide materials for outreach into the food chain and to citizens, and in some schools. It's not all-encompassing, but we are making real efforts to do that.

TR: Some agricultural biotech companies, such as Syngenta, have reduced or halted research in Europe due to consumer resistance and regulatory inactivity. How does the industry perceive current regulations?

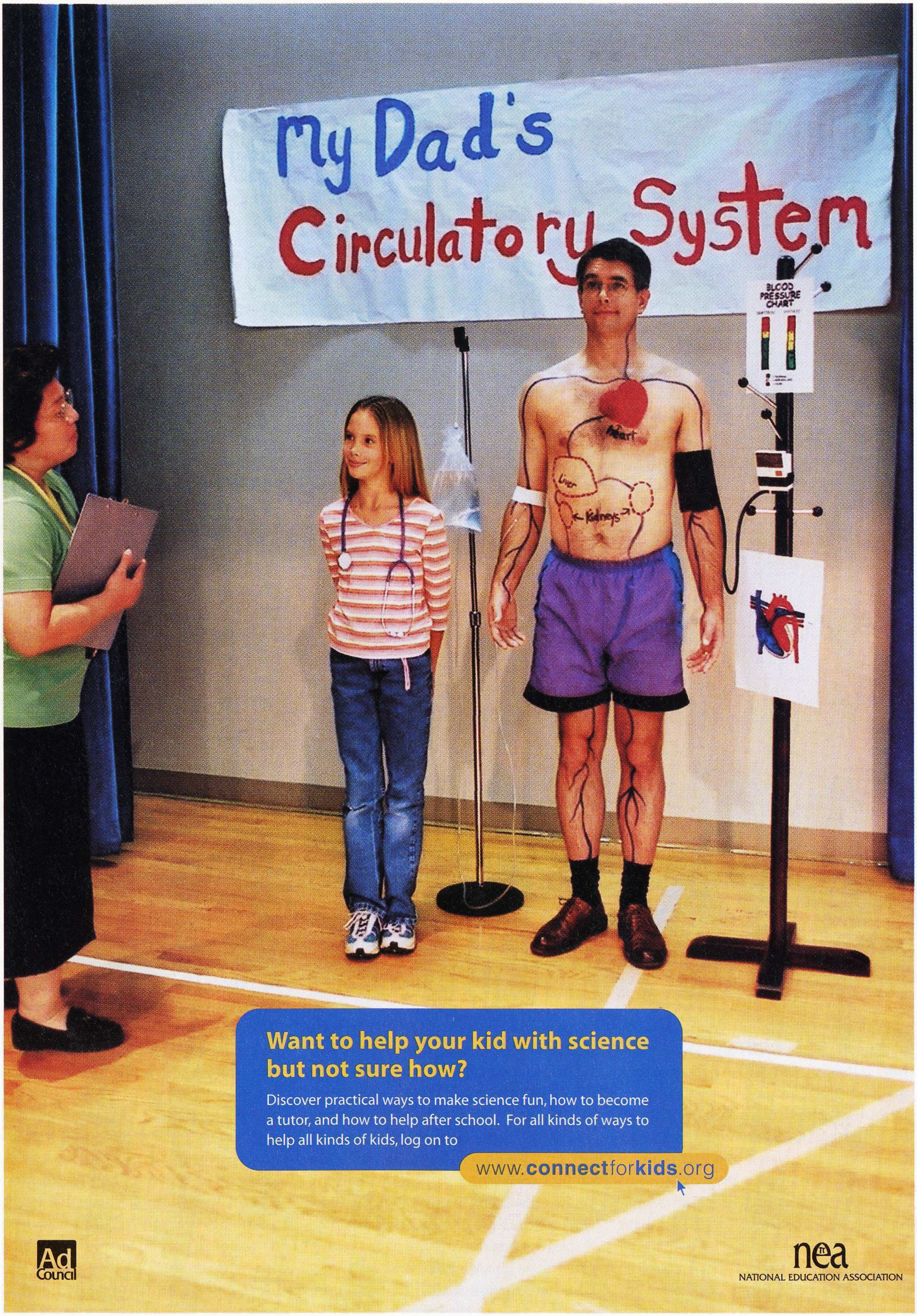
BARBER: I don't think that the regulatory machine in the EU is running consistently yet. If you're using this technology to develop a product and you want to have it on the market in 10 years, if the machine isn't running consistently, you never know whether you'll get your product to market. So perhaps one would move one's research somewhere else, where there's a history of consistent application of the regulation.

TR: Will some of these companies eventually return?

BARBER: Until the question of how the regulatory system is going to run—is it going to run at an even speed, or is it going to be run in a discriminatory way in some countries?—is sorted out, people will probably think very carefully about that. For instance, it's very difficult to do field trials here now. In the interest of transparency, researchers make the locations of field trials known, and many of them are destroyed every year by people with a conviction against anybody using the technology. So that is part of the judgment a company that is interested in using these technologies has to make about where it does its basic research. Europe is one of the centers of origin of this technology, in Belgium at Ghent University, 25 years ago. And I think it's a sad thing that not just industry but also the public institutions have been much reduced in their plant science activity because of the way things have gone here. Universities are finding people don't want to get involved in plant science because they don't see a future for it. But we still have a commitment from companies here to continue. Bayer CropScience, which is a German company, recently opened a new facility for plant science research in Belgium, for instance. The industry does want to see this move forward, and they really do think that plant science in Europe is important.

TR: Will GM foods and crops ever enjoy the acceptance level in Europe that they have in the United States?

BARBER: I would like to think so. It may be a good many years away. But if you look to see how the technology is being used to date, it's provided benefits to farmers. I think it's a very, very sad thing that a lot of people in the West living in urban areas don't perceive a benefit to a farmer as a benefit to themselves, because they are benefits to us. But this is also an opportunity to diversify the way we use plants to meet some other needs in a more environmentally sustainable way. I hope eventually we'll see Europe embrace the technology and move down these roads. It's a tool. We say "GM," and we think of one or two crops. But it's a tool that we can use to do a multitude of useful things. TR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Dual-Mode Vaccines

BY CORIE LOK

Vaccines are unarguably one of the greatest success stories in medical history, eliminating or largely curtailing numerous age-old scourges such as smallpox and polio. But researchers' track record in coming up with effective vaccines for today's major and emerging diseases is, by and large, dismal. A Yale University spinoff, Vaxinnate, hopes to use recent breakthroughs in basic immunology to reinvigorate vaccine development and create new vaccines for cancer, West Nile virus, and influenza.

In the last decade, immunologists have uncovered the biological mechanisms of a very different kind of immune reaction than the "adaptive" response they've long studied. This "innate" immune response kicks in within mere minutes of an infection. In contrast, the adaptive response, with its familiar antibodies, takes days to get up to fighting speed. An effective vaccine should elicit both types of responses, and researchers now understand that the vaccines of old—made with weakened live viruses—did just that. But to avoid the risks inherent in using live viruses, vaccine developers have turned to individual proteins as immune-system stimulators. Although they're safer and can generally boost antibody production, these vaccines often fail to prod the innate immune system to action.

Armed with new knowledge of innate immunity, Vaxinnate is working on vaccines aimed at kick-starting both types of responses. The company's approach is to fuse a protein that cranks up adaptive immunity with another that stimulates innate immunity. The result is a single entity that "would provide both signals that are necessary and sufficient to get an immune response to anything you want," says Yale immunologist Ruslan Medzhitov, Vaxinnate's scientific cofounder and one of the key discoverers of some of the biological underpinnings of innate immunity.

Fusing the two protein molecules "is a good idea," says Alan Aderem, director of the Seattle, WA–based Institute for Systems Biology. Injecting the two together without fusing them runs the risk of turning on too many immune cells, says Bruce Beutler, a professor of immunology at the Scripps Research Institute in La Jolla, CA. This in turn could cause excessive inflammation and lead to side effects like fever, rash, and in the worst case, shock. The fused proteins, on the other hand, would activate only a subset of cells—those bearing receptors for both proteins—which in turn would call to action both the innate and adaptive immune branches.

Founded in 2001, Vaxinnate has raised almost $25 million in venture capital and is now in early-stage animal testing of vaccine candidates for West Nile virus and influenza, with a leukemia candidate soon to follow. The company faces stiff competition on all three fronts from other research groups and companies, several of which are using conventional single-protein approaches. A number of cancer vaccines, for instance—including ones for leukemia—are already in mid- to late-stage human trials. Vaxinnate's goal is to begin human tests of whatever emerges as its leading candidate by 2006.

Technical hurdles also stand in the way. Even coupling the two proteins may not be enough to avoid side effects, says Beutler. That's because the subset of cells that the fused proteins interact with might not be narrow enough to exclude all of the culprits in inflammation reactions. Vaxinnate likely "would have to use some other trick," says Beutler, to further restrict the vaccine to just the right cells.

Even with such challenges, Vaxinnate is one of only a few companies striving to inject some of the new science of innate immunity into vaccine and drug development. Medzhitov hopes that at the very least, Vaxinnate will turn vaccine development—traditionally a trial-and-error process—into more of a science. TR

VAXINNATE

HEADQUARTERS:
New Haven, CT

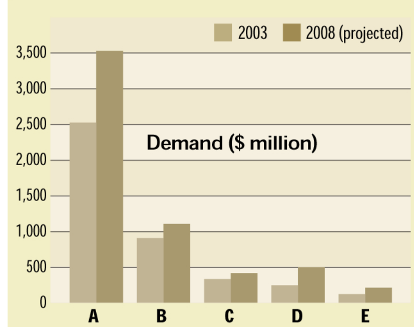
UNIVERSITY:
Yale

INVESTMENT RAISED:
$25 million

LEAD INVESTOR:
HealthCare Ventures

KEY FOUNDERS:
Ruslan Medzhitov, Richard Flavell

TOP-SELLING U.S. VACCINES



A Pediatric (including polio, measles/mumps/rubella, tetanus/diphtheria)
B Hepatitis (including hepatitis A and B)
C Biodefense (including smallpox and anthrax)
D Influenza
E Travel (including rabies, typhoid fever, yellow fever)

SOURCE: THE FREEDONIA GROUP (VACCINES)

OTHERS IN INNATE IMMUNITY

COMPANY	TECHNOLOGY
Coley Pharmaceutical Group (Wellesley, MA)	Drugs that induce a receptor involved in innate immunity to attack cancer cells; in mid-stage human trials
Corixa (Seattle, WA)	Innate-immunity drug administered nasally for seasonal allergies; in early-stage clinical trials
Inimex Pharmaceuticals (Vancouver, British Columbia)	Drugs that boost expression of innate-immunity genes to combat bacterial infections; in early animal studies
Innate Pharma (Marseilles, France)	Drugs and antibodies that induce specific elements of the innate immune response to kill cancerous cells

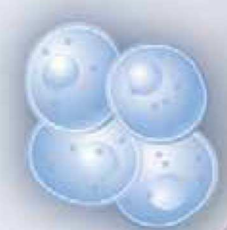
Preimplantation Genetic Diagnosis

Preimplantation genetic diagnosis (PGD) is a state-of-the-art diagnostic procedure used with in vitro fertilization to test embryos for genetic disorders. It is also used to detect aneuploidy (the wrong number of chromosomes) and other chromosomal abnormalities, which result in birth defects, cognitive disabilities, early miscarriage, and implantation failure. About 1,000 babies worldwide have been born following PGD. The procedure—which can add \$3,000 to \$5,000 to the \$8,000 to \$12,000 cost of in vitro fertilization—raises new ethical questions beyond those already surrounding in vitro fertilization: should PGD be used to select gender or behavioral characteristics, or to select a genetically matched sibling who could act as a tissue donor for a sick older brother or sister? Regulations for its use differ by country: for example, it is legal and practiced in the United States and the United Kingdom, and illegal in Austria, Germany, and Switzerland. Meanwhile, new methods of diagnosis are evolving that might, for instance, one day allow for the analysis of all the chromosomes in an embryo at the same time. (PGD is currently limited to examining a handful of chromosomes per embryo.) This would allow for the identification of vastly more abnormalities and traits in a given embryo—and would raise still more questions. **TEXT AND ART BY 5W INFOGRAPHIC**

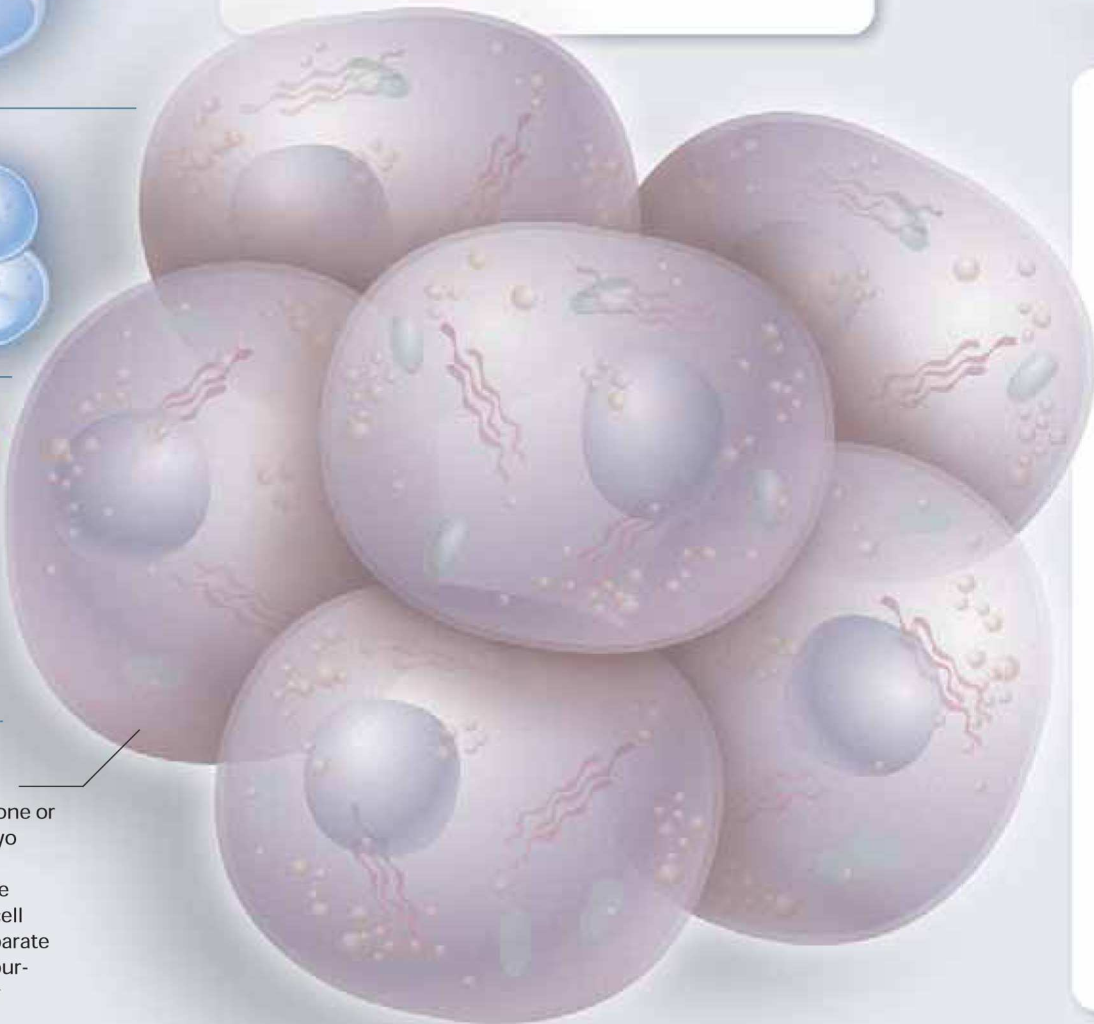
Before diagnosis: in vitro fertilization

1 EGG FERTILIZATION
Hormones are used to stimulate a woman's ovaries. About 12 eggs are surgically removed and fertilized in the laboratory. The preferred fertilization method is the injection of a single sperm directly into the egg.

2 EGG-CELL DIVISION
Successfully fertilized eggs are allowed to divide and multiply for three days, at the end of which they will each contain six to eight cells.



3 REMOVAL OF A SINGLE CELL
One or two cells called blastomeres are plucked from the developing embryo with a suction pipette. These cells are analyzed for gene or chromosome abnormalities. The most common and reliable procedure to detect a chromosomal abnormality is called fluorescent in situ hybridization (*see "Detecting the diseases"*).



EIGHT-CELL EMBRYO Research has shown that it is possible to remove one or two cells from an 8- to 10-cell embryo without harming its development (though the long-term effects on the child are not yet known). At the 16-cell stage, it becomes too difficult to separate individual cells, and at the two- or four-cell stage, removal threatens further development.

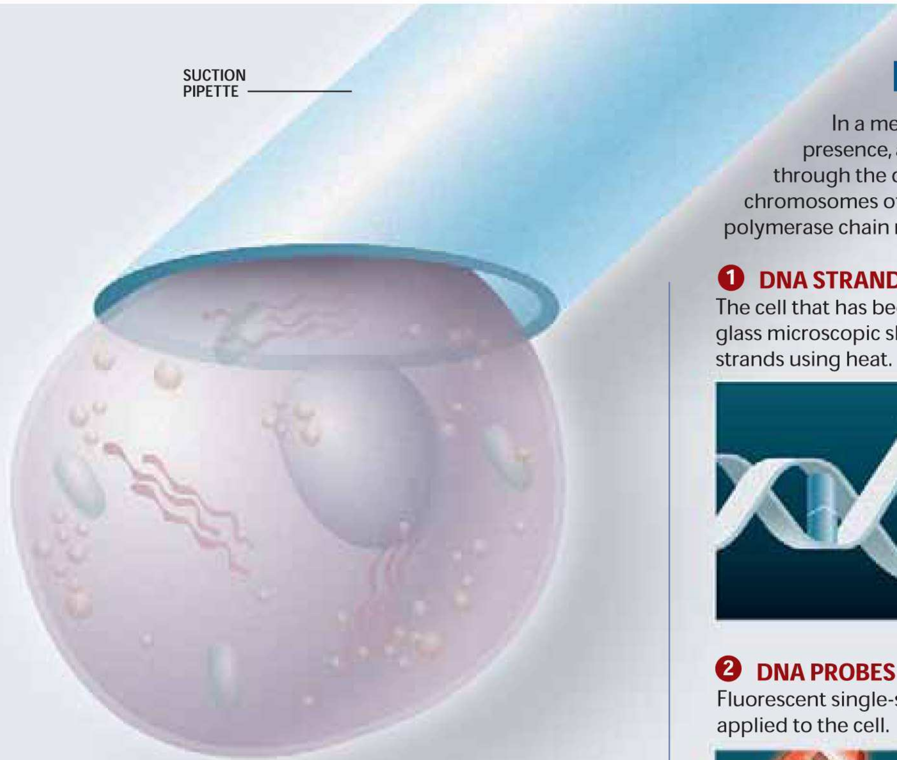
Who can benefit from PGD?

Couples with a history of inheritable genetic disease

Women who have had recurrent miscarriages

Couples who have had repeated in vitro fertilization failures

Couples with chromosomal abnormalities that can cause implantation failure, miscarriages, and mental or physical problems in offspring



Diseases that can be identified with PGD

PGD can potentially screen for over 200 diseases, which fall into three categories:

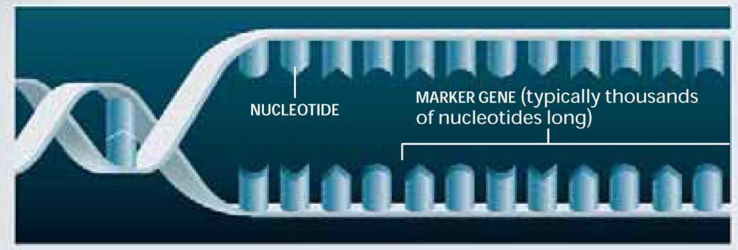
- **Aneuploidy, chromosomal rearrangements, and other chromosomal abnormalities** may result in birth defects such as Down syndrome, miscarriage, or implantation failure. These abnormalities affect about six of every 1,000 babies born; about 60 percent of reproductive losses are associated with chromosomal abnormalities.
- **Sex-linked disorders** are genetic abnormalities found on either the X or Y chromosome and so typically affect only one gender. With PGD, only embryos of the sex that is not affected with a specific disorder are transferred into the uterus and allowed to develop into a pregnancy. Sex-linked disorders affect approximately one to two of every 1,000 births and include hemophilia, fragile X syndrome, Rett syndrome, and many neuromuscular dystrophies.
- **Single-gene disorders** affect about one in 200 children. Examples include cystic fibrosis, Tay-Sachs disease, sickle cell anemia, and Huntington's disease.

In the future, PGD may be able to detect genes that predispose people to common diseases such as cancers.

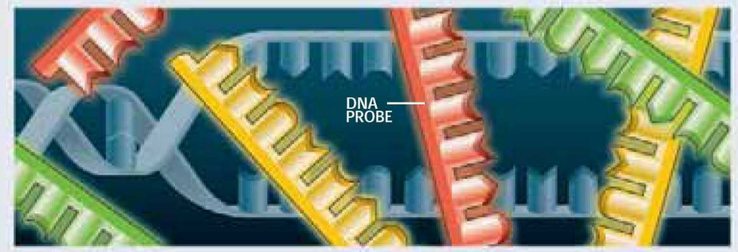
Detecting the diseases

In a method called fluorescent in situ hybridization (FISH), the presence, absence, or excess of specific chromosomes is determined through the detection of marker genes that reside on the chromosomes of interest. (For single-gene defects, a method called polymerase chain reaction is used instead.)

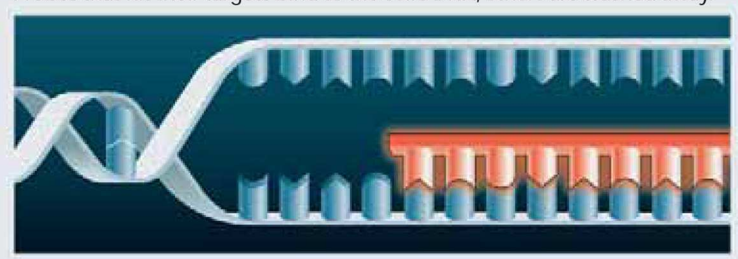
1 DNA STRANDS ARE SEPARATED
The cell that has been separated from the growing embryo is placed on a glass microscopic slide. The double helix of the DNA is separated into single strands using heat.



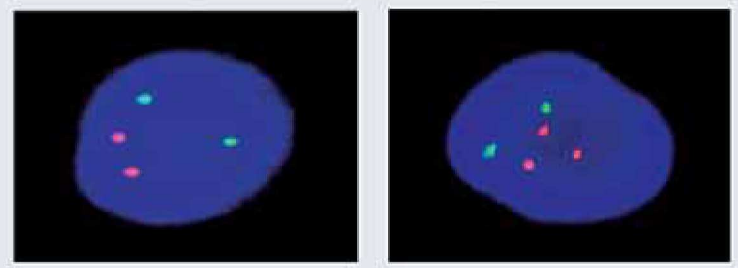
2 DNA PROBES ARE ADDED
Fluorescent single-stranded DNA probes that target the marker genes are applied to the cell.



3 HYBRIDIZATION
Probes that hit their targets bind to the cell's DNA; others are washed away.



4 UNDER THE MICROSCOPE
All chromosomes in an embryo should come in pairs. When illuminated under a microscope, the fluorescent probes glow, revealing either normally (left) or abnormally (right) paired chromosomes. The cell on the right is from an embryo with an extra chromosome 21, or Down syndrome.



Screen Test

WITHIN THE NEXT FEW YEARS, ACTIVE SCREENS are going to be mounted on the walls of most households. We'll use them for entertainment, we'll use them for information, but most of all, we'll use them to communicate without words. ▪ Many households will have those 30-inch to 60-inch plasma displays—screens that are dropping in price and turning up on the walls of more and more family rooms.

While today's screens are great for watching television and DVDs, I expect that in the not-too-distant future, many will be showing family photos and even video feeds from romantic locations when they are not otherwise occupied. Why look at a blank screen when you can gaze at a lifetime's worth of snapshots of your children or shots of your upcoming vacation destination in Bali?

I envision that, in the kitchen or near the front door, the favored screens will be 20-inch, high-resolution liquid-crystal displays with built-in Wi-Fi adaptors. These information-rich appliances could display things like weather predictions and traffic reports when you are heading out in the morning, then tastefully switch to great works of art to greet your eyes when you arrive home.

Granted, there is no application that I foresee for these wall-mounted screens that wouldn't work on a desktop computer today. But the advantage of intelligent screens is that they would always be ready and stocked with the information you need. The simplicity of just glancing at the wall will win out over the complexity of desktop computing.

I have had a primitive version of such a "smart screen" on my wall for four years now: it's one of those moving-message LED signs, which I rigged to display news clippings from CNN and the Weather Channel. The reports are incredibly useful: I catch news out of the corner of my eye that I simply would have missed if I had been forced to fiddle with a Web browser.

It's surprisingly more enjoyable to view your digital camera's photos in an attractive frame on the wall than on a desktop screen.

A more sophisticated smart screen is Visart's Album TV, which I had hanging on my kitchen wall this past fall. This piece of techno wizardry, which looks like an oversized picture frame, lets you watch TV as well as play DVDs and CDs on its built-in drive. But what's really different about the Album TV is that it also has a reader that will show photographs or movies stored in any of the popular flash memory formats. It's surprisingly more enjoyable to view your digital camera's photos in an attractive frame on the wall than on a desktop screen. Visart sells screens in a variety of sizes; the 18-inch version I tested goes for $995.

The key advantages of an integrated machine are sleekness and simplicity. The Album TV has only a power cord and a conventional remote control, making it simple to play a DVD or watch a slide show. Unfortunately, the screen also suffers from the pitfall of having been designed by a consumer electronics firm: it lacks the sort of flexibility that computer users expect. For example, it will display a slide show of photos that are stored on a Compact Flash memory card, but it won't display those same images if you burn them onto a CD or DVD and pop it in the drive. Data is data, you might think—but Visart's designers didn't see it that way. One annoyance: you can set the slide show to change images every one, three, five, or 10 seconds—but not every five minutes, which is more what you'd want for a wall-mounted picture frame.

That's why I am hoping that the "smart screen" market will be driven by computer vendors instead. An interesting step in this direction is Apple Computer's decision to offer a VESA (Video Electronics Standards Association) mounting bracket for the back of its sleek new G5 iMac computers. This is a big deal: it's very difficult to securely mount traditional desktop LCD panels on a wall, because most of them have attached stands that get in the way.

Because wall-mounted PCs and Macs run standard operating systems, it will be much easier for developers to create a wide range of "post-PC" applications for them. Cables are ugly, so get your electrician to install a recessed outlet—the same kind of outlet that would be installed for an electric clock—and use a wireless 802.11 network to enable the wall-mounted computer to get data from your home server or the Internet.

Interestingly, it was Microsoft's Bill Gates who pioneered the idea of using wall-hanging computer screens as ever changing electronic frames. Back in 1994, Gates announced that electronic "windows" would be built into his house overlooking Lake Washington near Seattle. Gates also founded Corbis to purchase the electronic rights to millions of photographs. Corbis bought the Bettmann Archive in 1995 and the Sygma news photo agency in 1999, as well as electronic rights to the works of many museums—assuring in the process that the walls inside the Gates estate would never be at a loss for pretty electronic pictures.

These days, of course, anybody with a cheap digital camera has plenty of electronic images and few places to display them. Hence one of the many advantages of hanging an electronic picture frame on your wall. TR

Simson Garfinkel is an incurable gadgeteer, an entrepreneur, and the author of 12 books on information technology and its impact.

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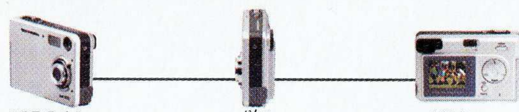

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Longest battery/picture-taking time

Other digital cameras gobble up batteries almost as fast as a child can eat a bag of potato chips. Not the Bell+Howell®. It uses a very long lasting rechargeable lithium-ion battery, which will give you about 2 hours of continuous picture taking on a full charge.

Ultra small with tremendous built in memory

This camera is almost as small as a credit card. It's so small it can even fit in your shirt pocket. Yet it has an amazing 16 MB of built-in flash memory to store up to 109 photographs depending on resolution. Preserve nearly a lifetime of photographs by using the camera's SD card slot for removable memory cards.

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Capture those once-in-a-lifetime events in movie mode: baby's first steps, accepting a diploma, catching the wedding bouquet. You get 85 seconds of streaming video with built-in flash memory (30 seconds is the norm) and as much as 12 minutes on a 128 MB memory card (not included).

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At the Pentagon, Richard Kershner explains the workings of the Transit Navigational System, on the day its first satellite is launched into orbit.

Space Tracker

The earliest satellite watchers' ideas led to GPS. **BY DAN CHO**

OVER THE PAST DECADE OR so, the Global Positioning System has grown from a military navigation tool to a near ubiquitous tracking system. Biologists use it to follow migrating animals, while motorists depend on it to avoid getting lost on highways. But while the system's wide availability has sparked an explosion in innovative applications, satellite navigation itself can be traced back to the first satellite in orbit: Sputnik.

On October 4, 1957, the Soviet Union launched its famous orbiter, beating the United States into space and shocking the world with its technological prowess. For 23 days, Sputnik circled the globe emitting a radio signal, a constant beep that could be heard by anyone tuned to its frequency.

A few days after Sputnik's launch, physicists William Guier and George Weiffenbach at the Johns Hopkins Applied Physics Laboratory set up a receiver to listen for its signal. Because of the Doppler effect, the tone they heard varied slightly in frequency as the satellite passed overhead. The men realized they could use this shift to calculate Sputnik's position relative to their receiver and soon were able to accurately predict Sputnik's path.

A few months later, Guier and Weiffenbach were called before their boss, Frank McClure, who asked them to reverse the Sputnik tracking problem: use a known orbit and the same Doppler shift to calculate the position of a ground receiver. McClure envisioned a handful of satellites that continually broadcast their coordinates to submarines at sea, whose onboard computers would determine the vessels' locations every few hours, whenever a satellite passed above. After Guier and Weiffenbach confirmed that the idea was feasible, McClure and another Hopkins scientist, Richard Kershner, outlined what would be known as the Transit Navigational System.

In 1960, the first Transit satellite entered orbit. In 1967, the government opened the system to civilian ships and surveyors, who soon constituted the majority of users. The Transit program was gradually replaced by GPS—a different tracking method that employs many more satellites and does not require any waiting time to pinpoint position. The Transit system was retired in 1996, after more than 30 years of successful service. TR

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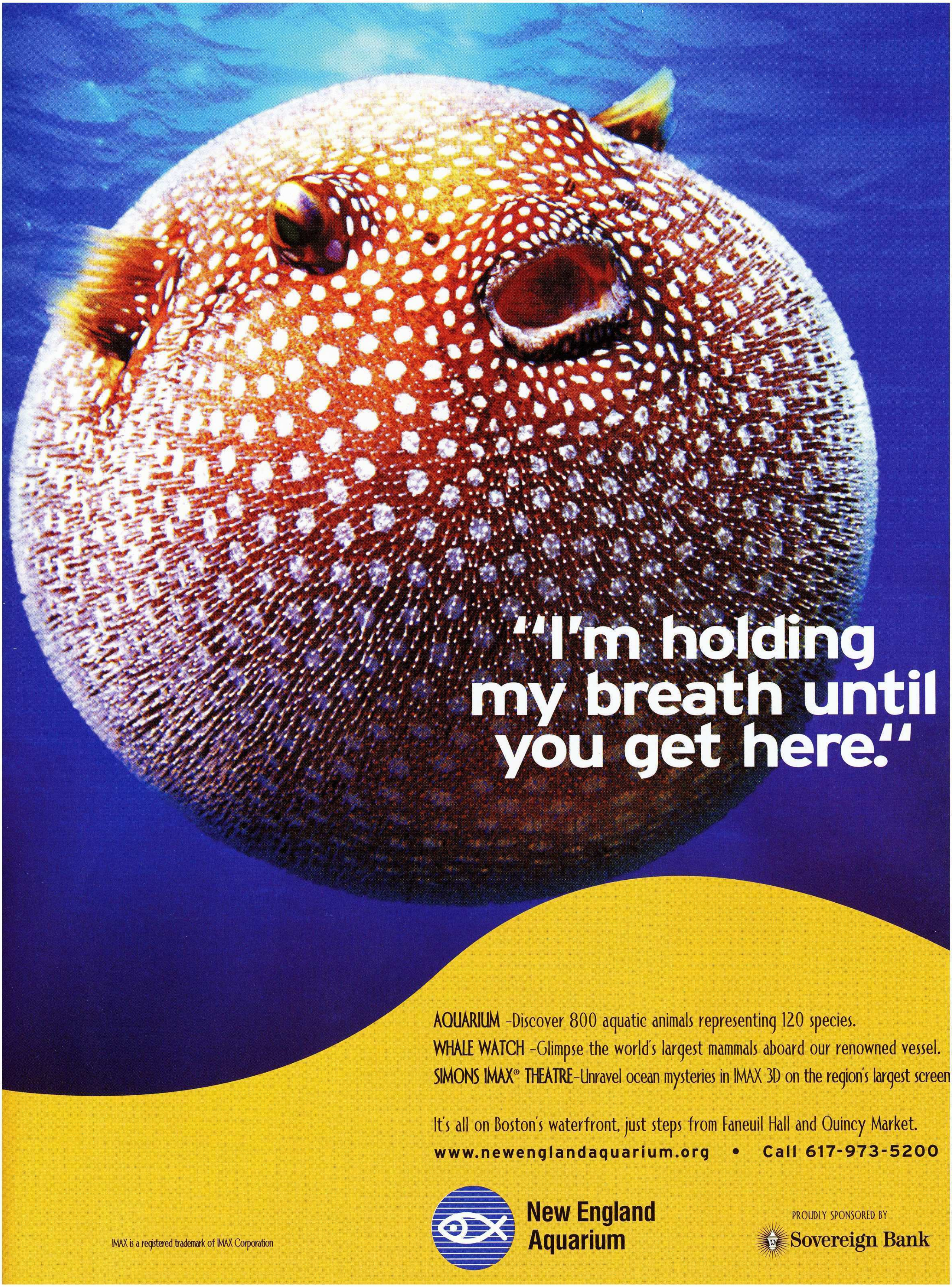
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